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**Chun-Hung et al.**

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(54) **LIGHT-EMITTING DEVICE**

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(51) **Int. Cl.**

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**H01L 33/60** (2010.01)  
**H01L 33/44** (2010.01)  
**H01L 33/48** (2010.01)  
**H01L 33/58** (2010.01)  
**H01L 25/075** (2006.01)  
**H01L 33/54** (2010.01)

(52) **U.S. Cl.**

CPC ..... **H01L 33/387** (2013.01); **H01L 33/44** (2013.01); **H01L 33/60** (2013.01); **H01L 25/0753** (2013.01); **H01L 33/486** (2013.01); **H01L 33/54** (2013.01); **H01L 33/58** (2013.01)

(58) **Field of Classification Search**

CPC ..... H01L 33/387; H01L 33/60; H01L 33/44; H01L 33/58; H01L 33/54

USPC ..... 257/98  
See application file for complete search history.

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*Primary Examiner* — Georgia Y Epps

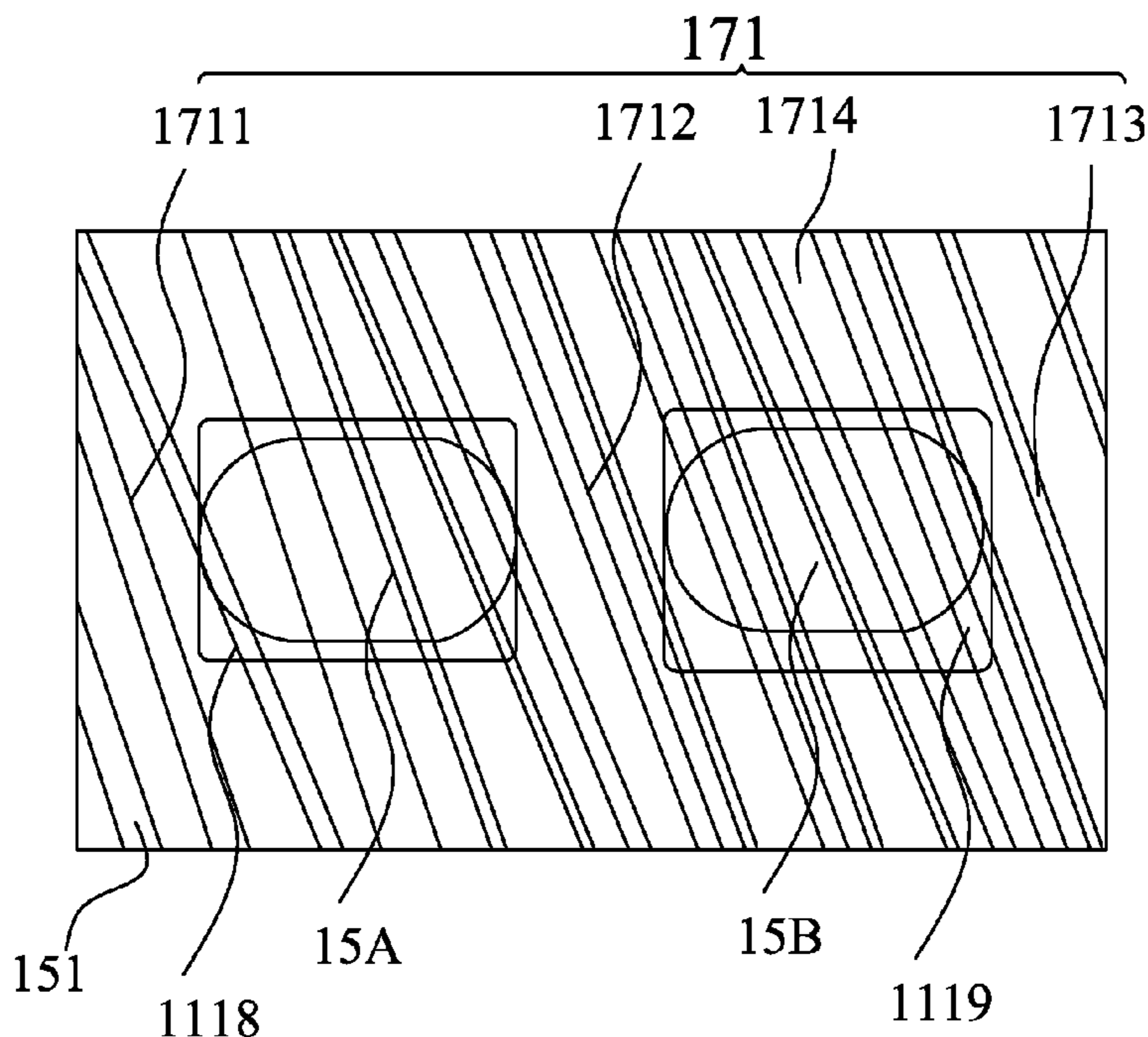
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(57) **ABSTRACT**

A light-emitting device includes a light-emitting structure with an electrode layer, a light-transmitting body, a reflective layer and a metal bump. The light-transmitting body covers the light-emitting structure, and has a first side surface and a second side surface which are substantially perpendicular to each other. The reflective layer covers the first side surface without covering the second side surface. The metal bump is directly formed on the electrode layer.

**14 Claims, 12 Drawing Sheets**







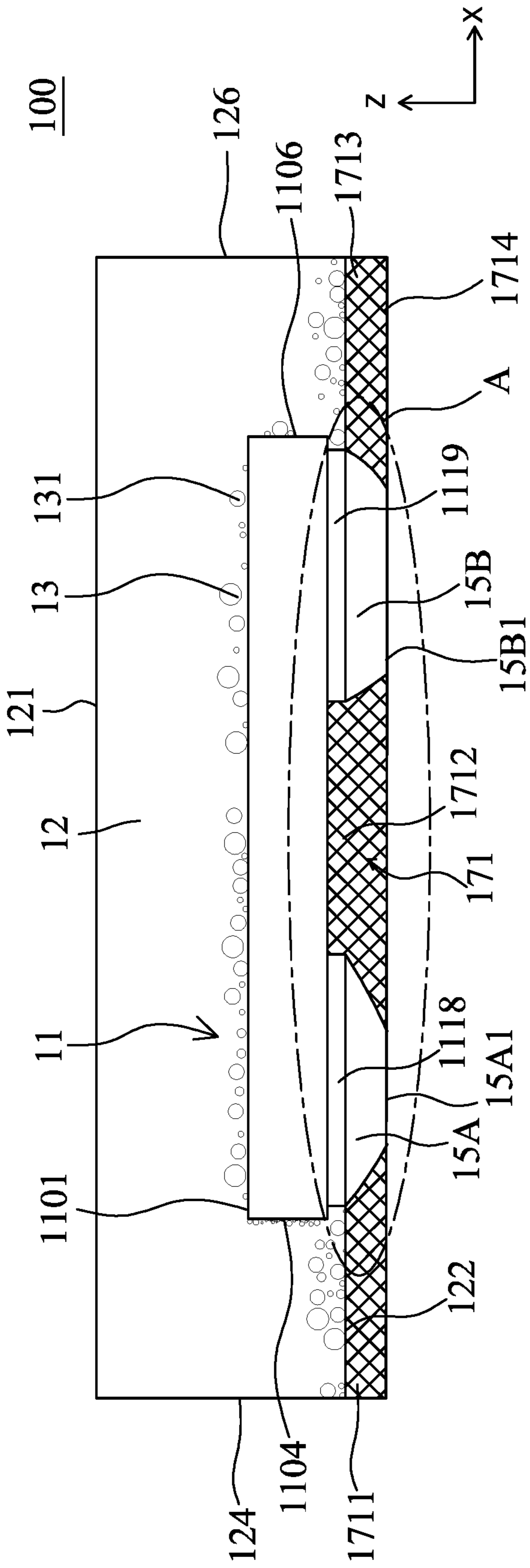


FIG. 1B

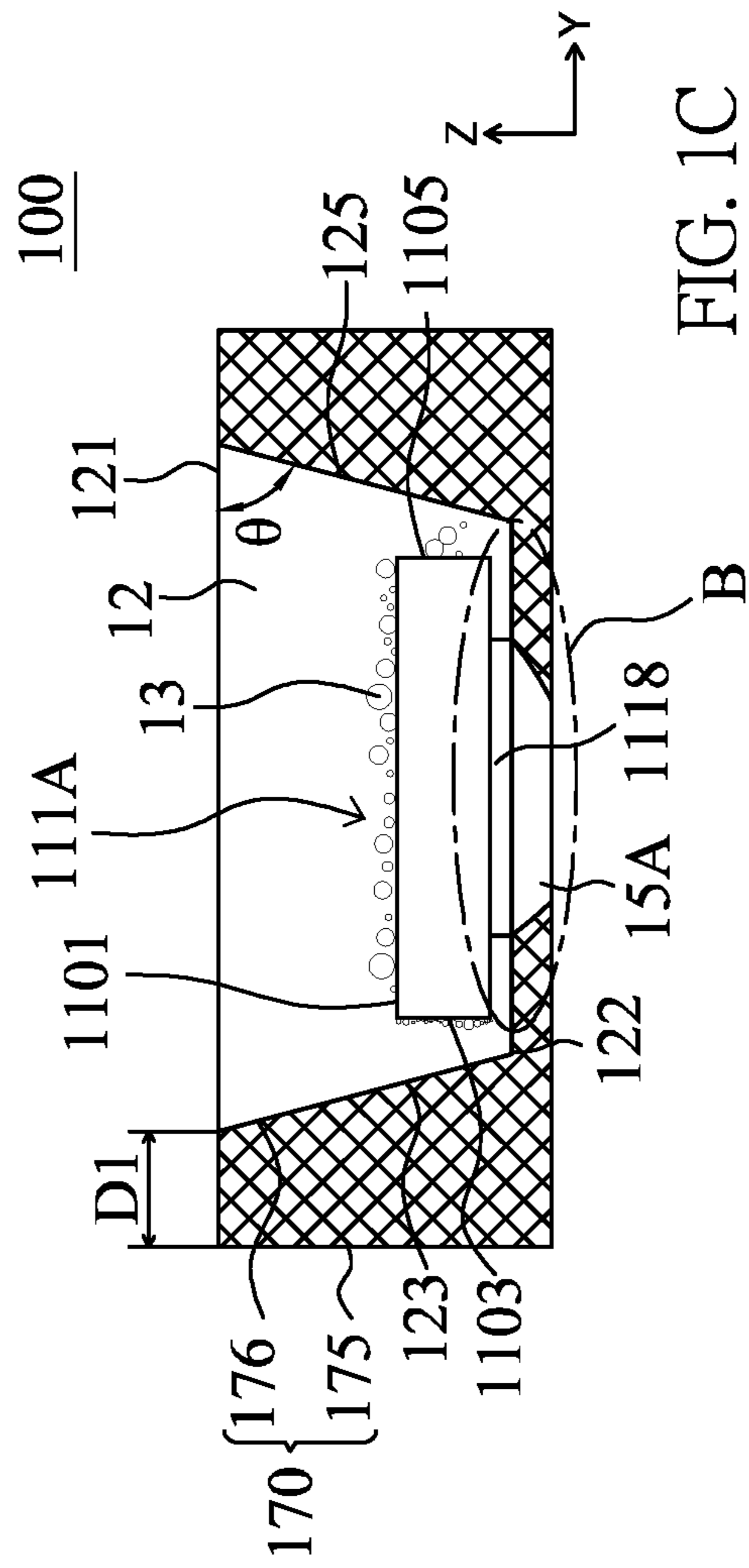


FIG. 1C

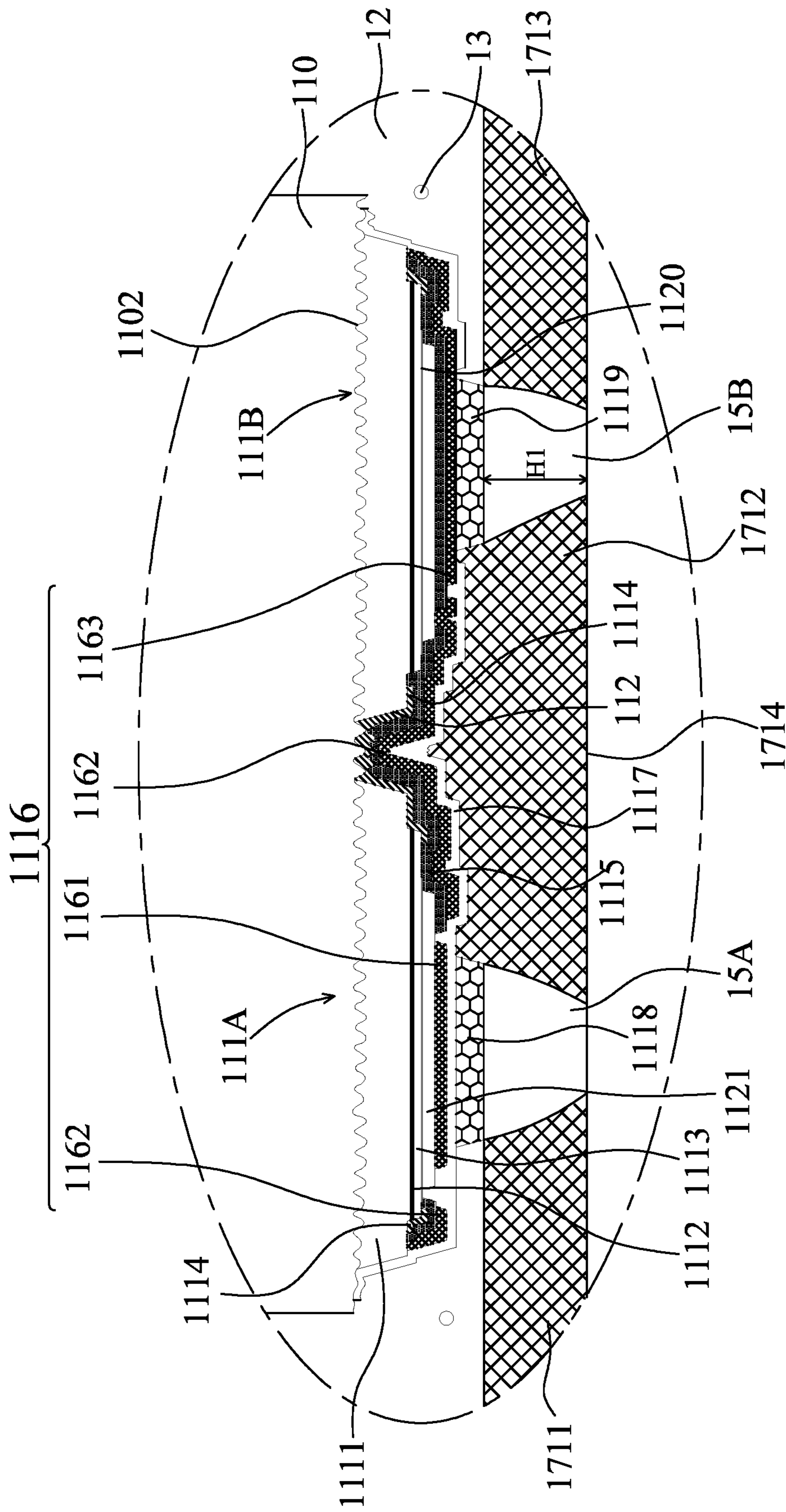


FIG. 1D

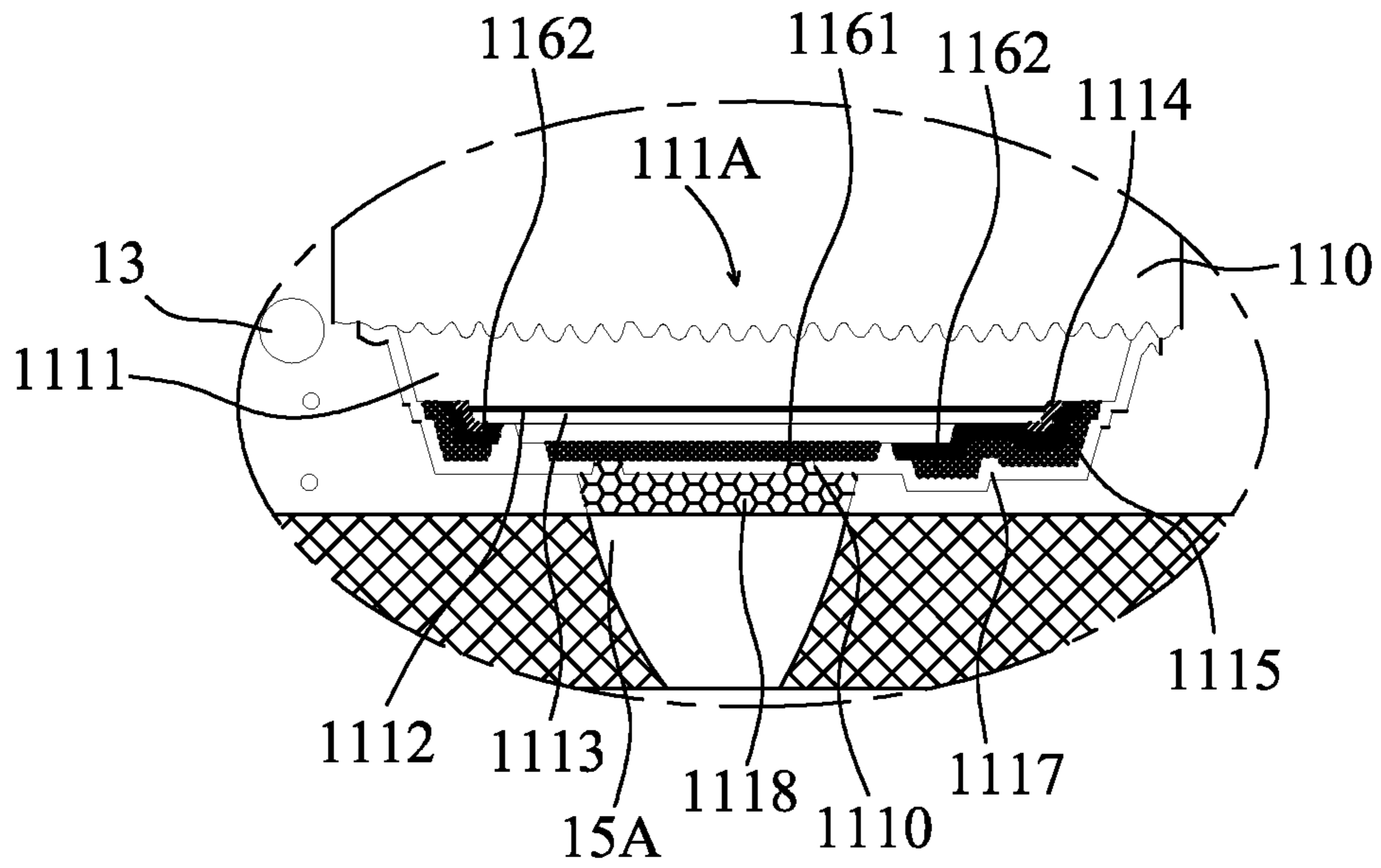


FIG. 1E

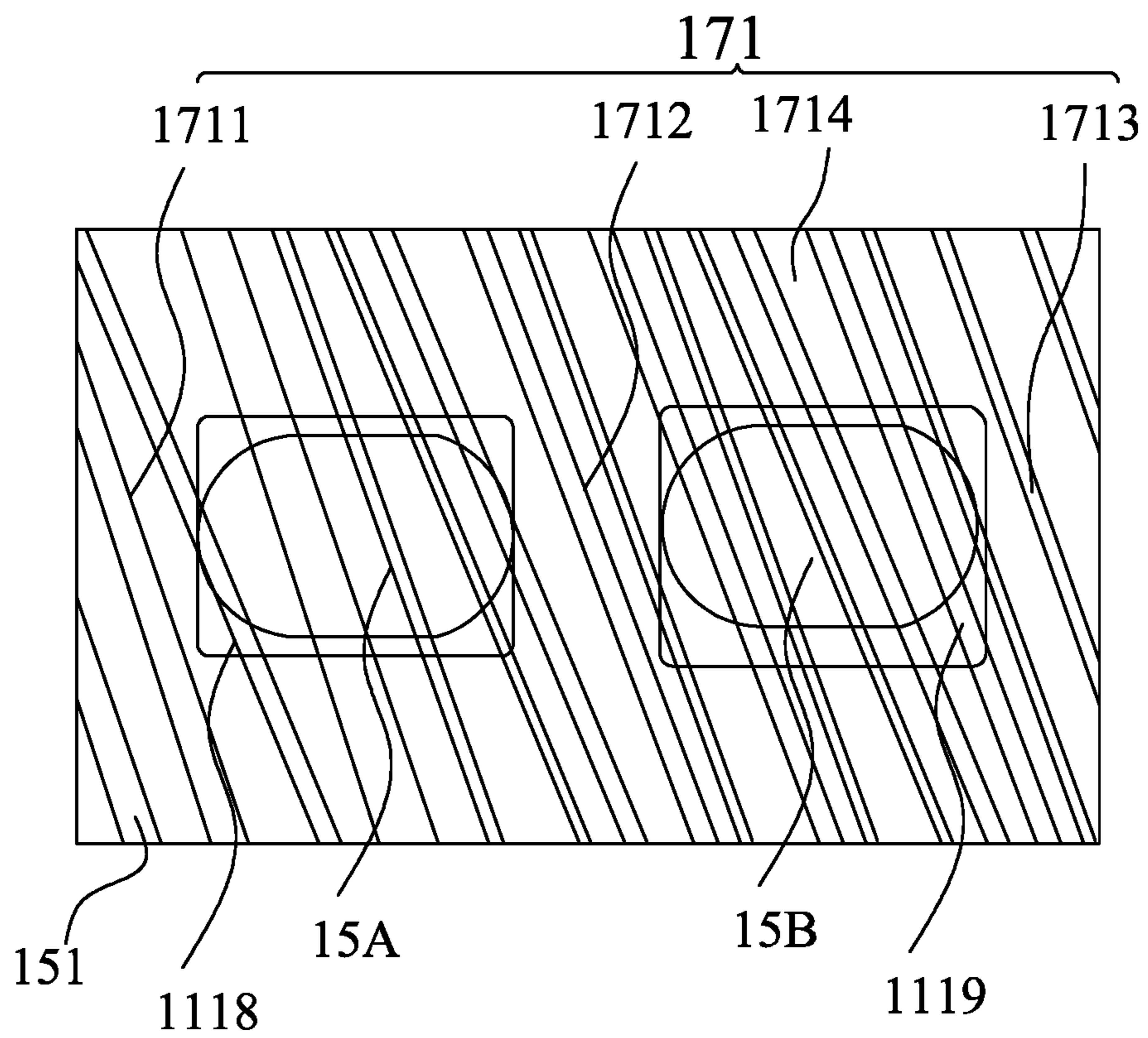


FIG. 1F

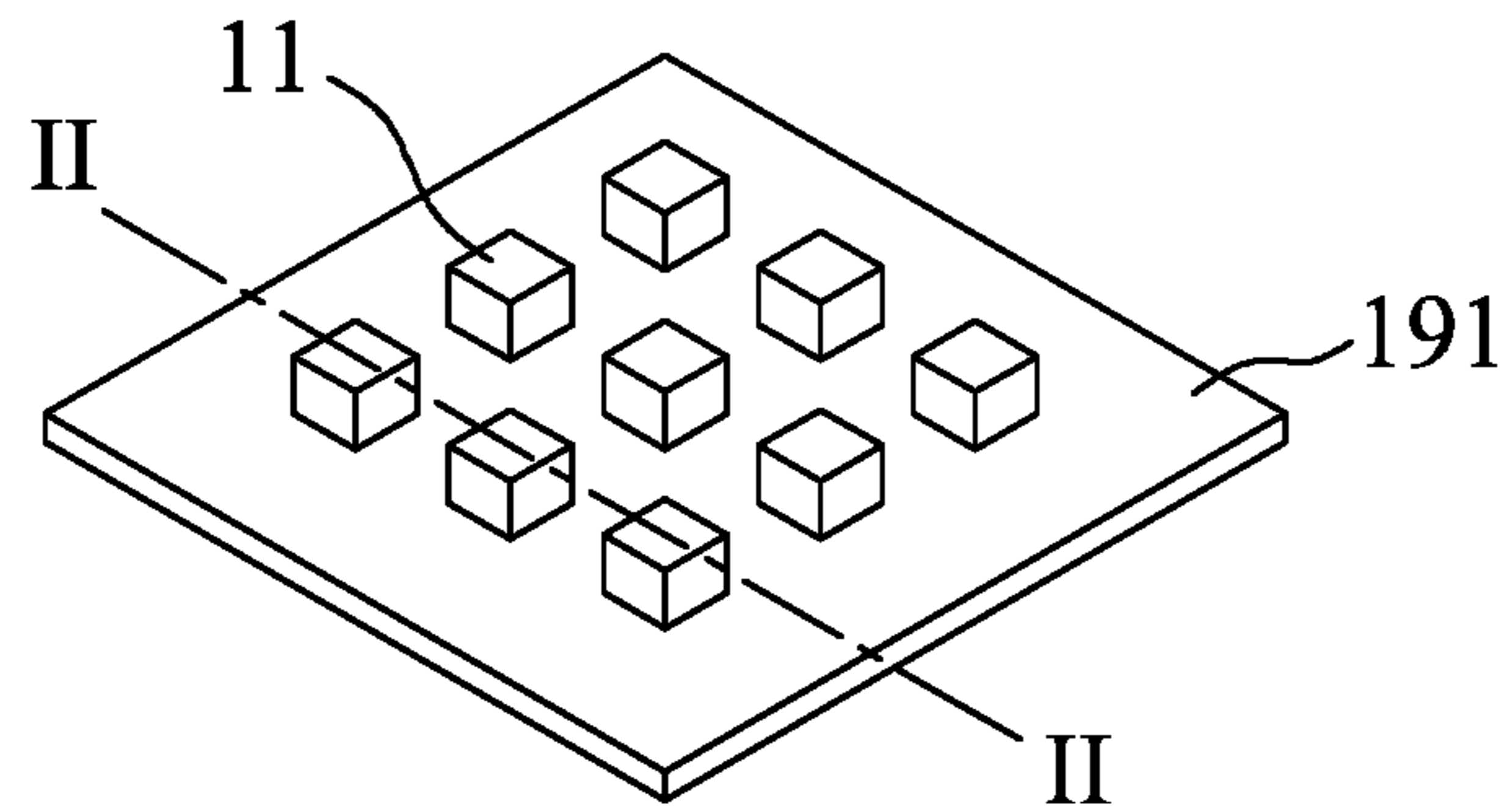


FIG. 2A

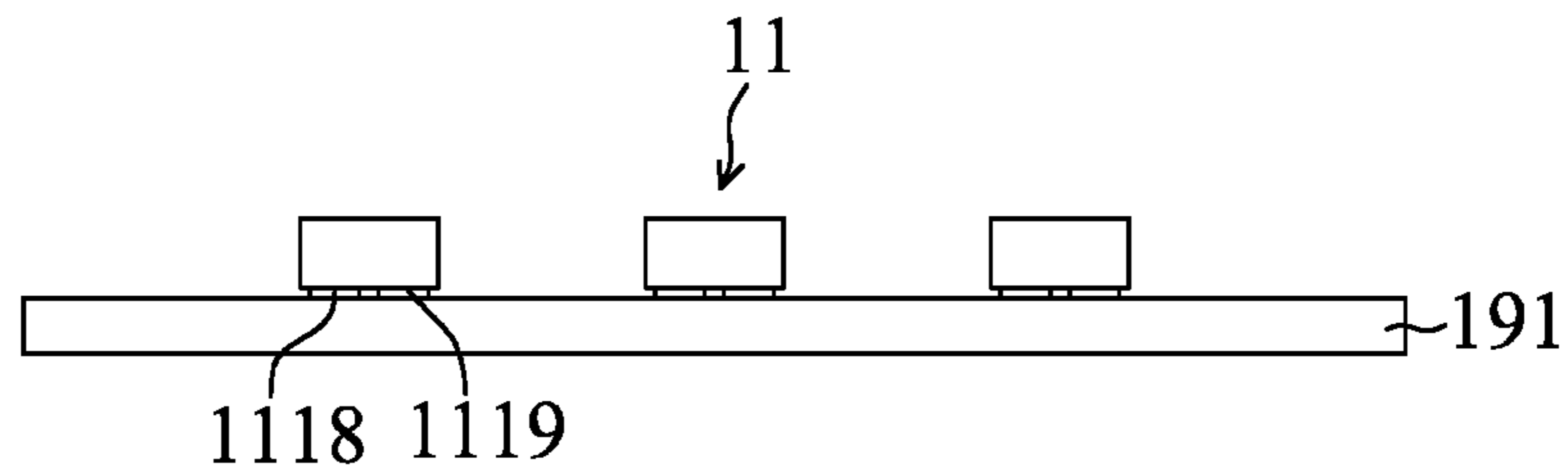


FIG. 3A

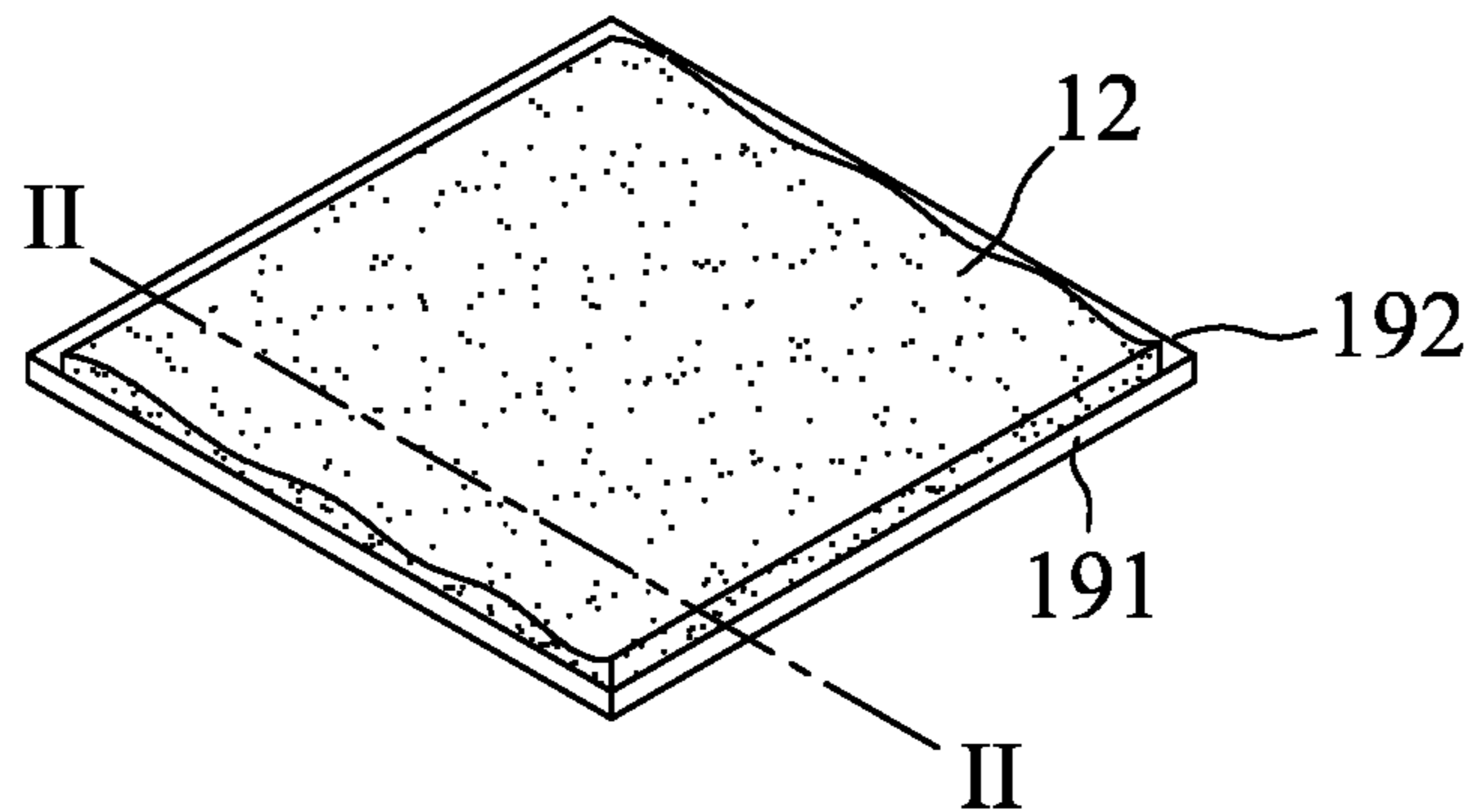


FIG. 2B

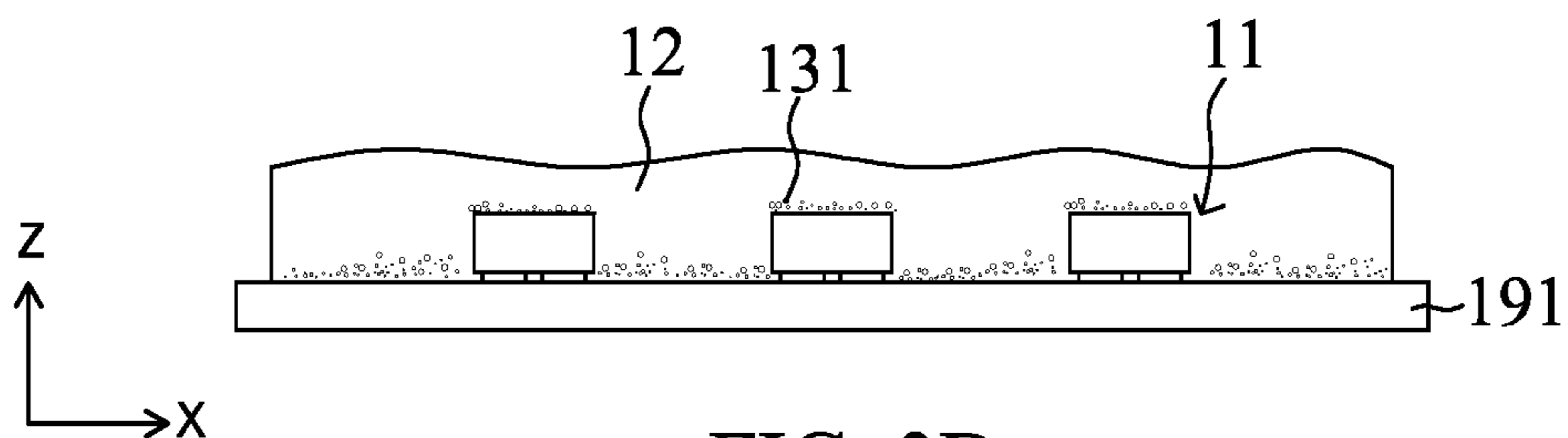


FIG. 3B



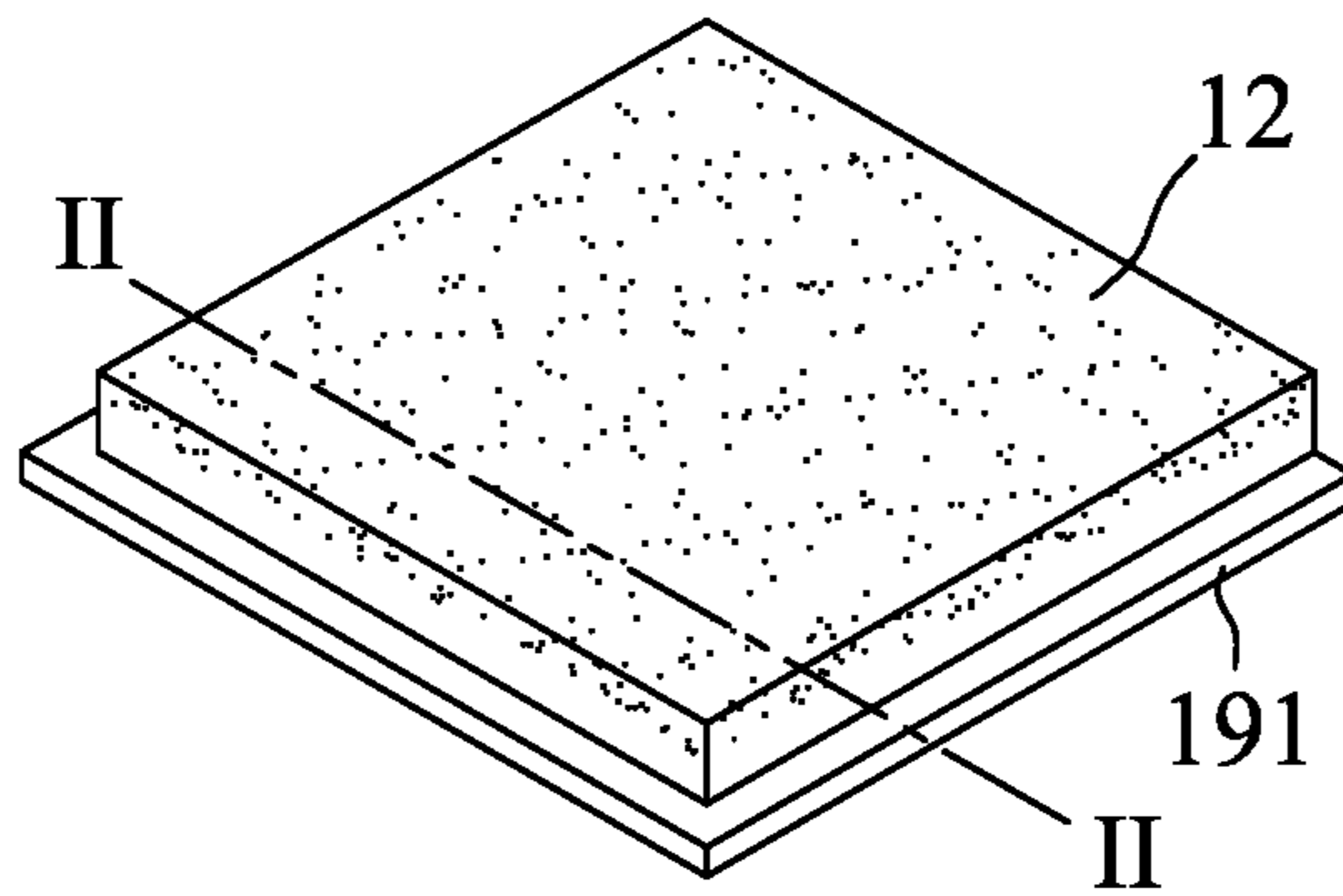


FIG. 2C

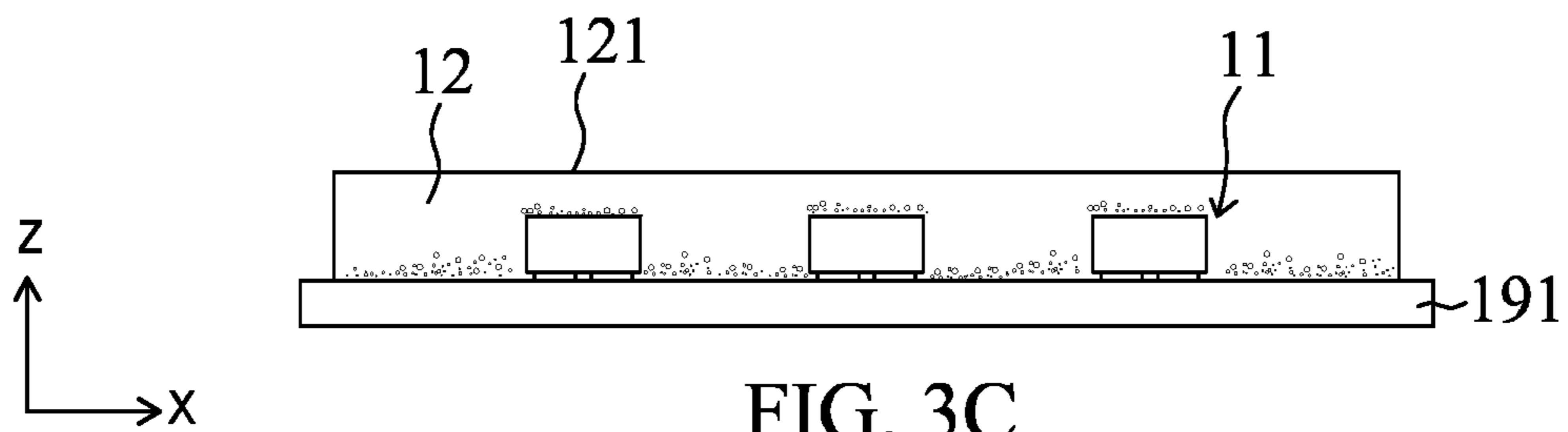


FIG. 3C

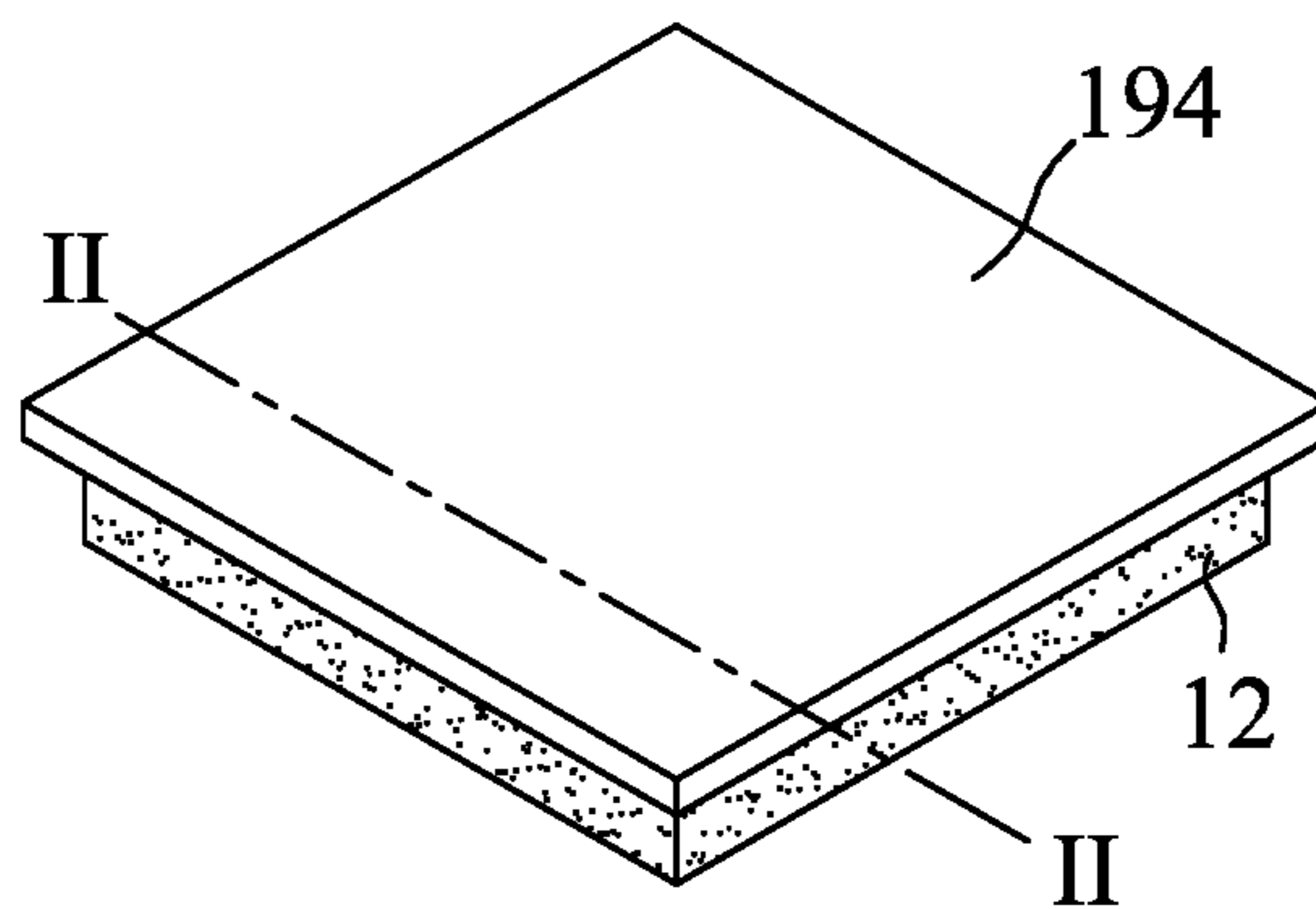


FIG. 2D

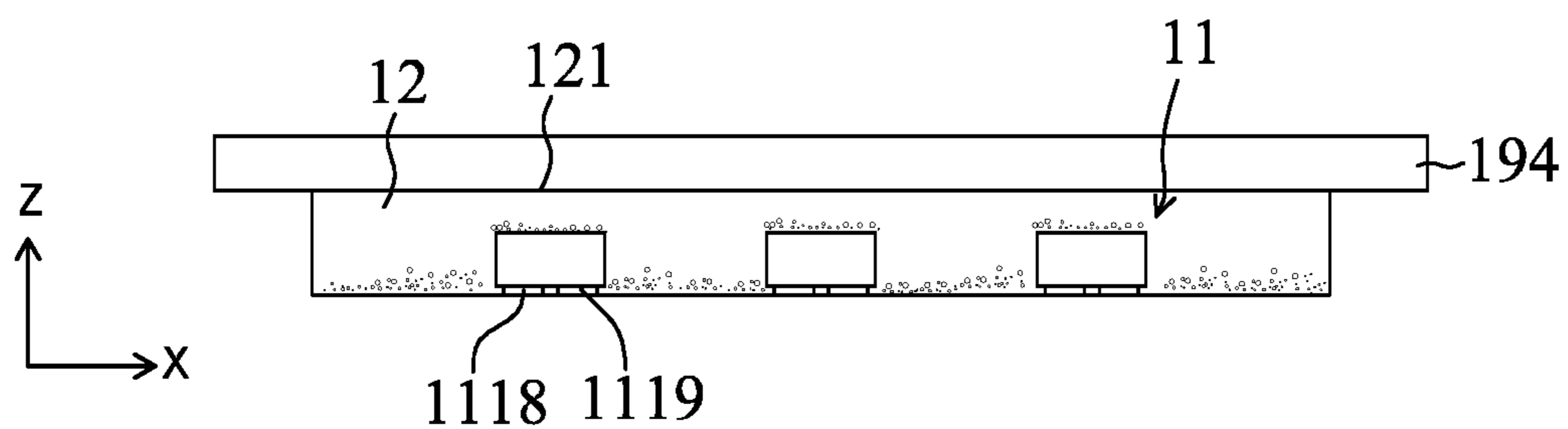


FIG. 3D

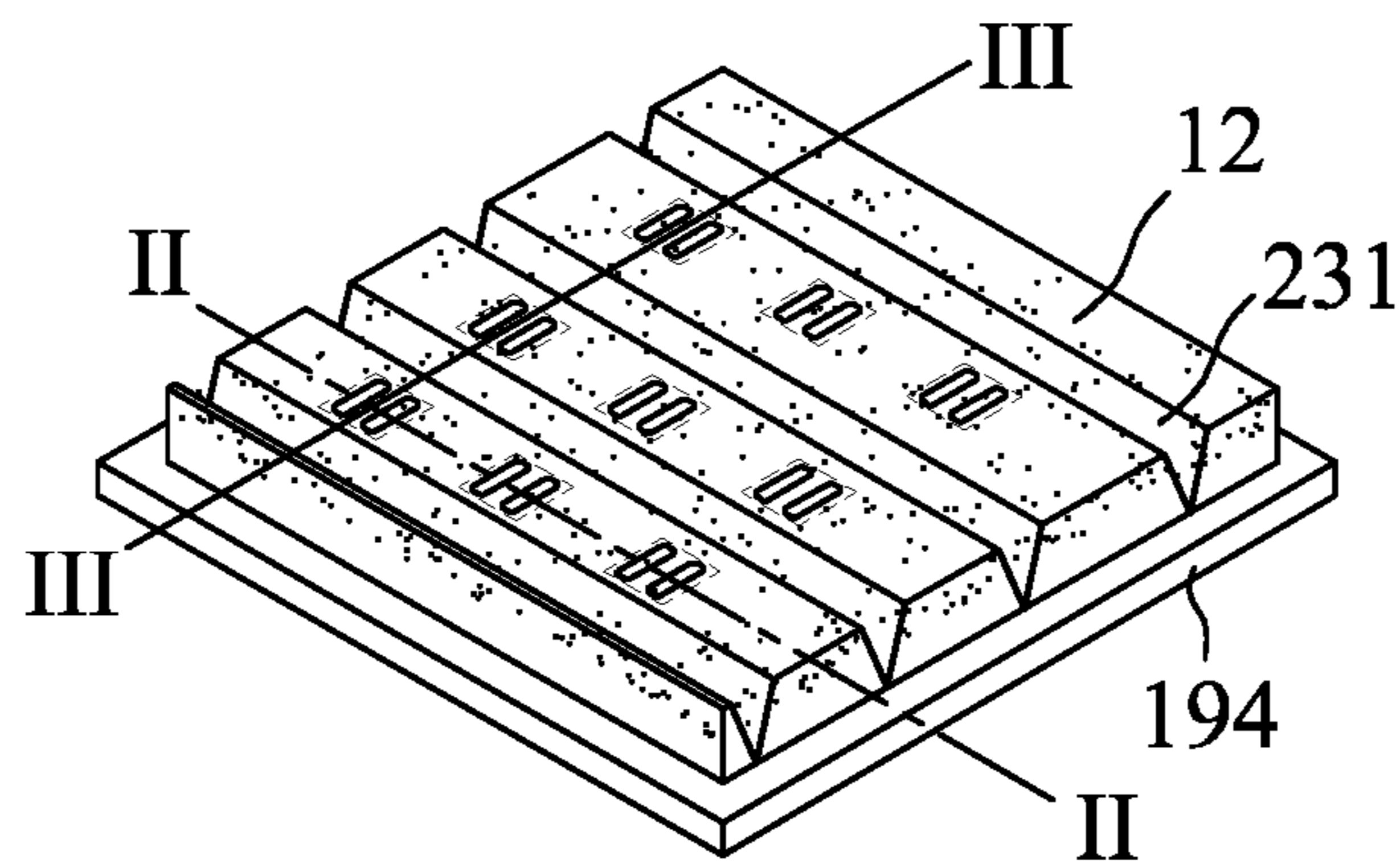


FIG. 2E

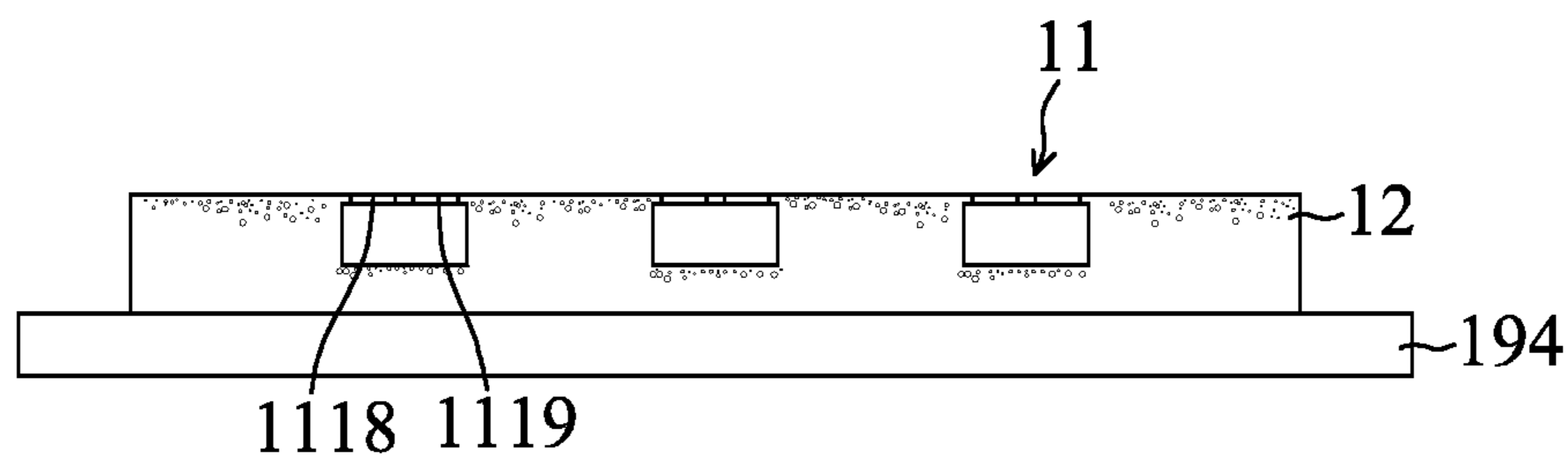


FIG. 3E

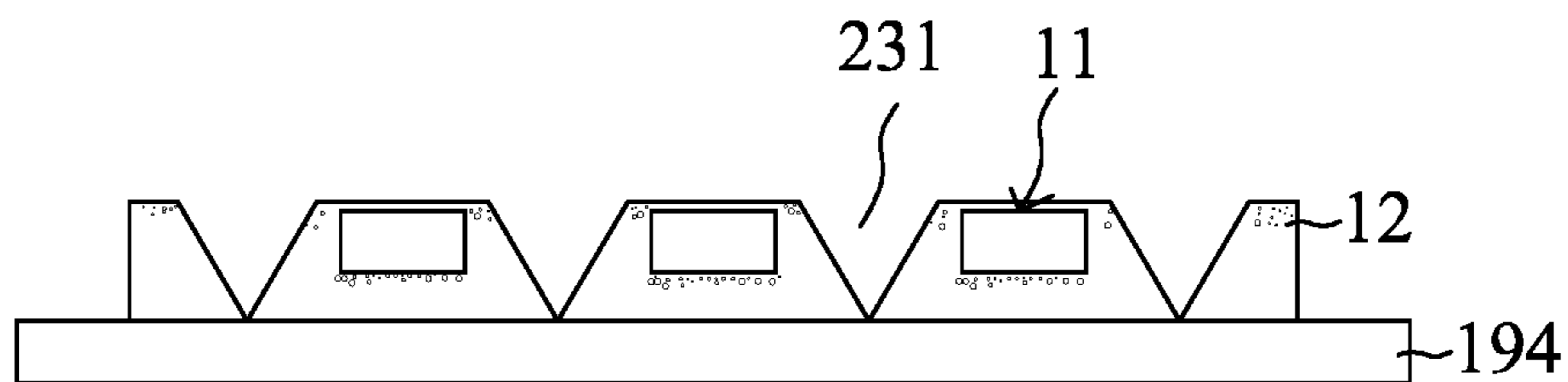


FIG. 4A



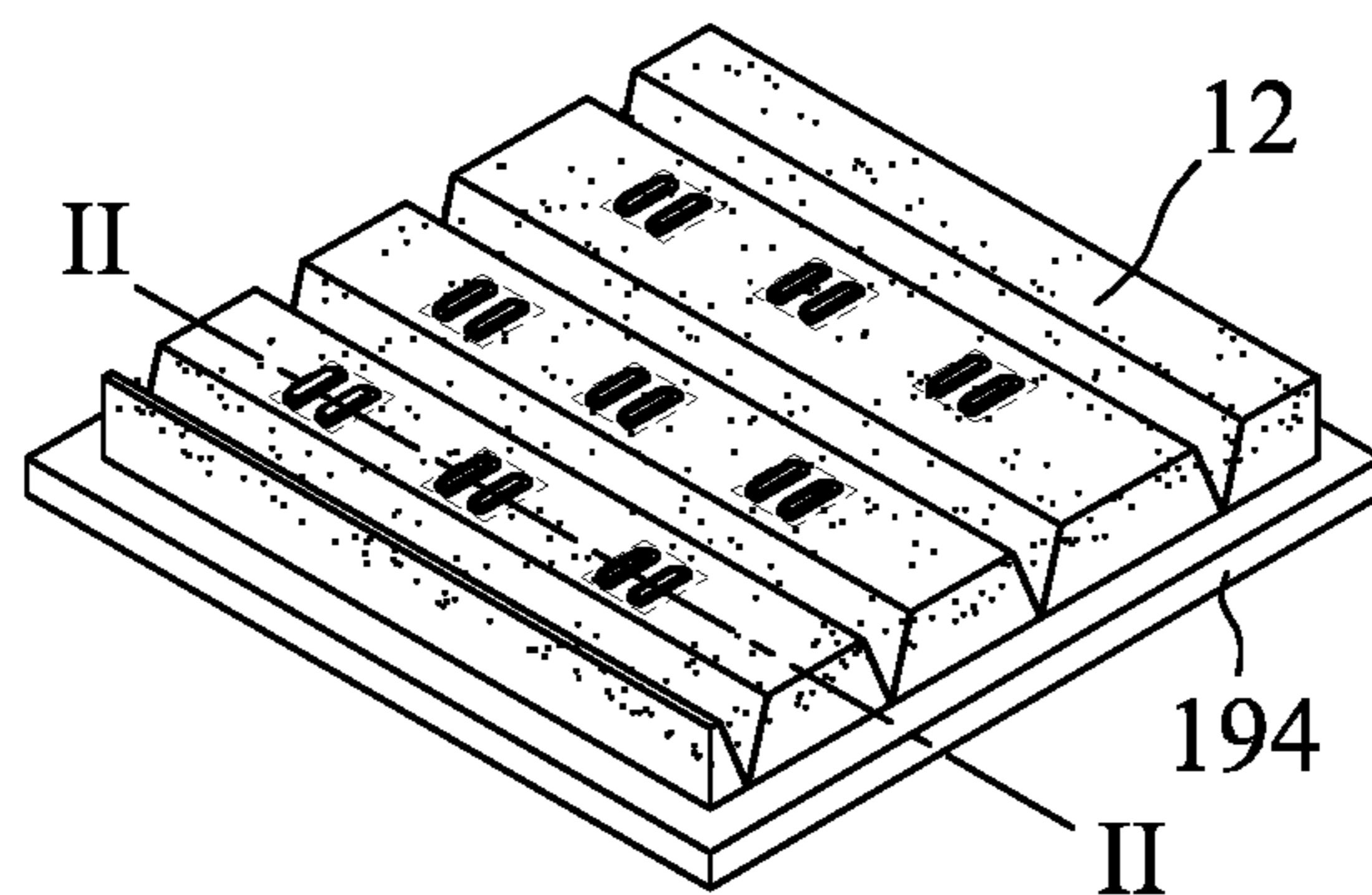


FIG. 2F

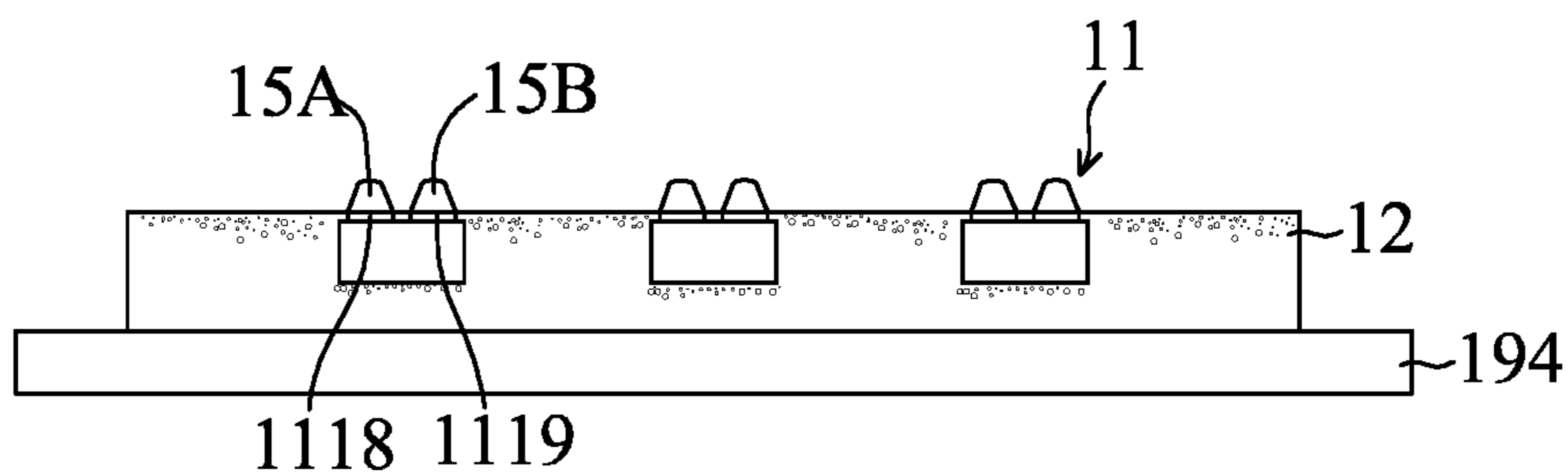


FIG. 3F

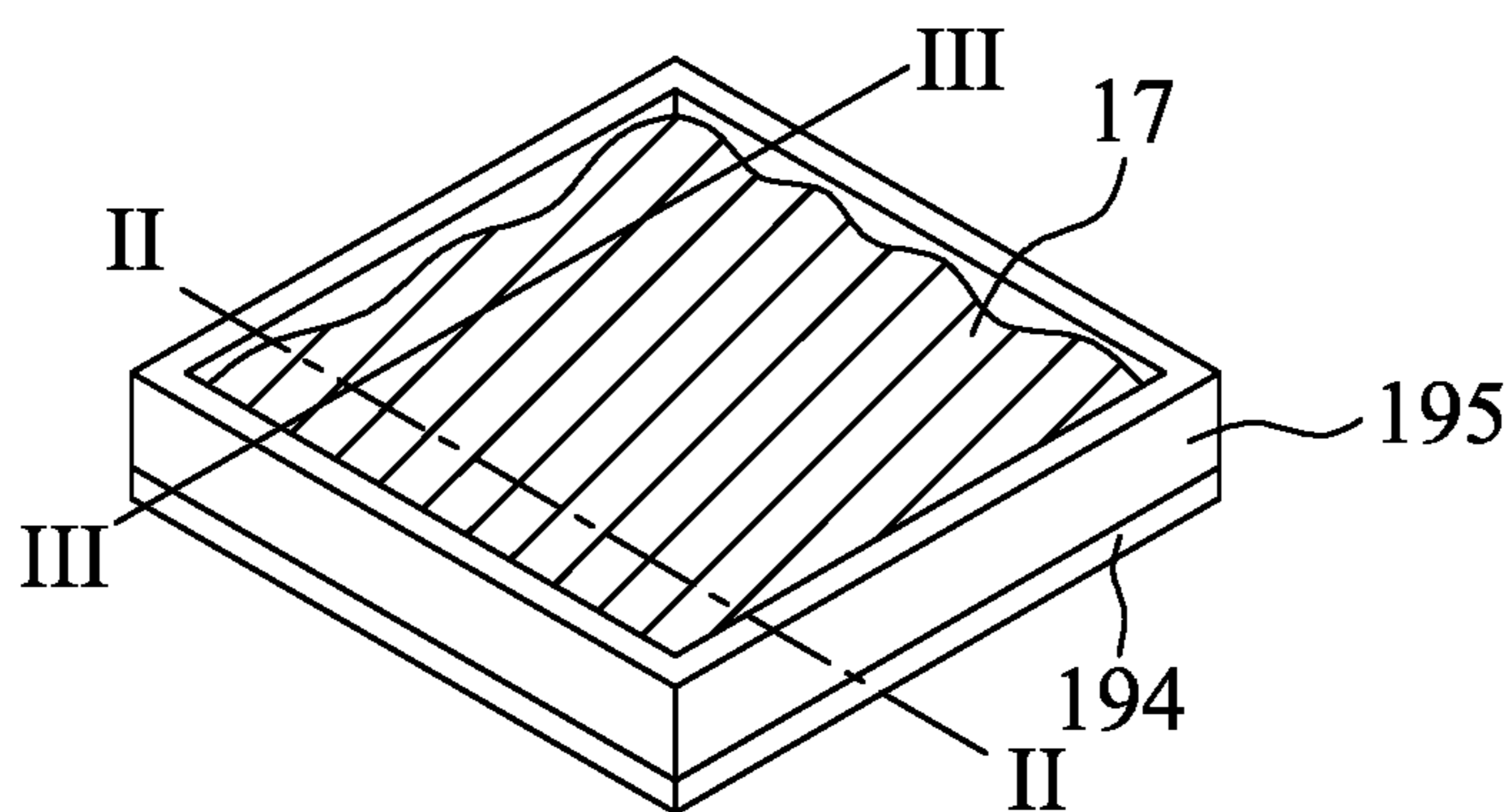


FIG. 2G

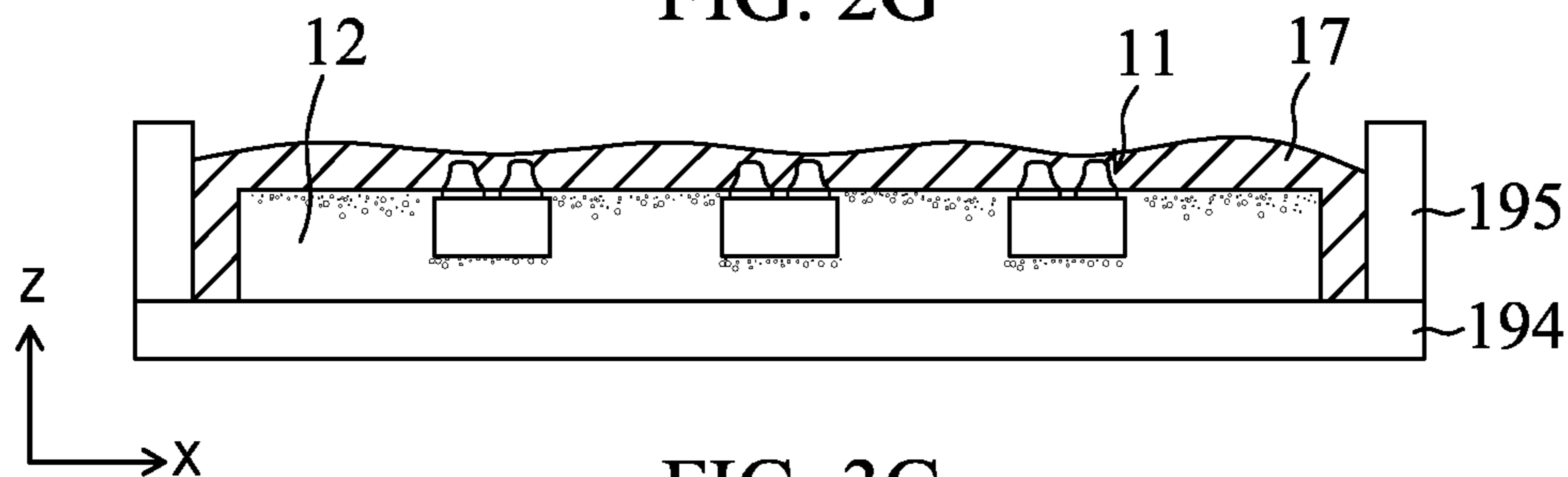


FIG. 3G

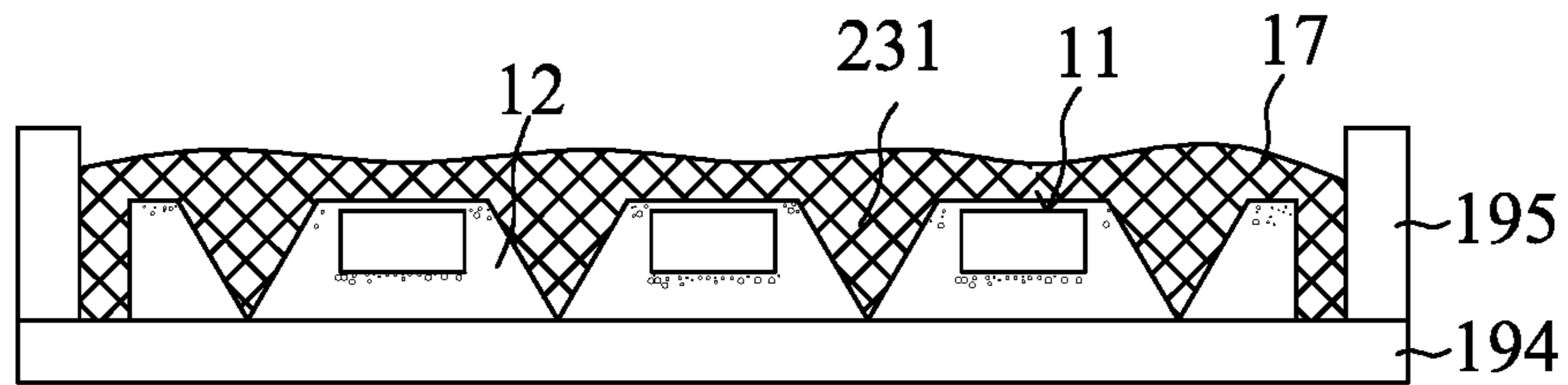


FIG. 4B

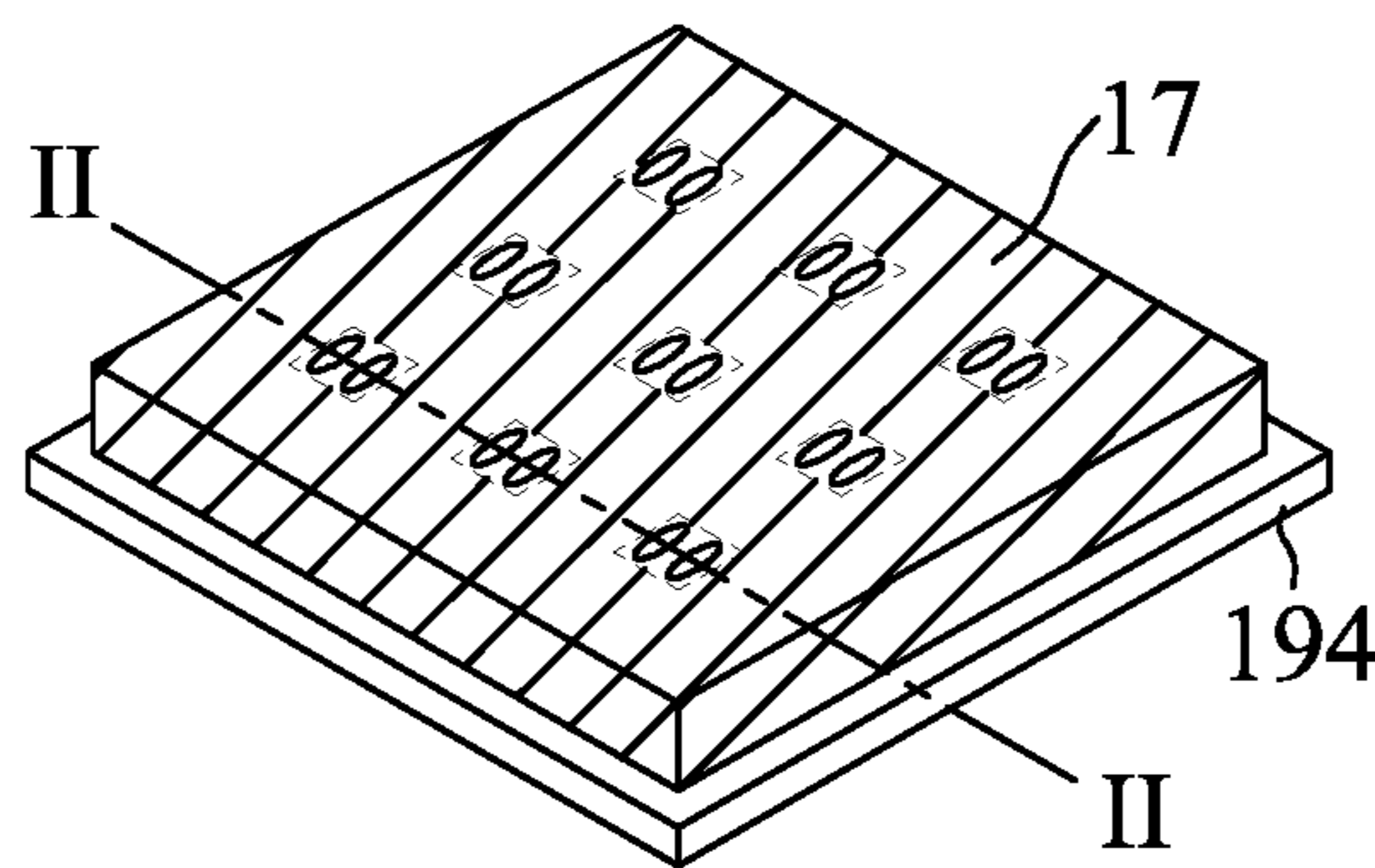


FIG. 2H

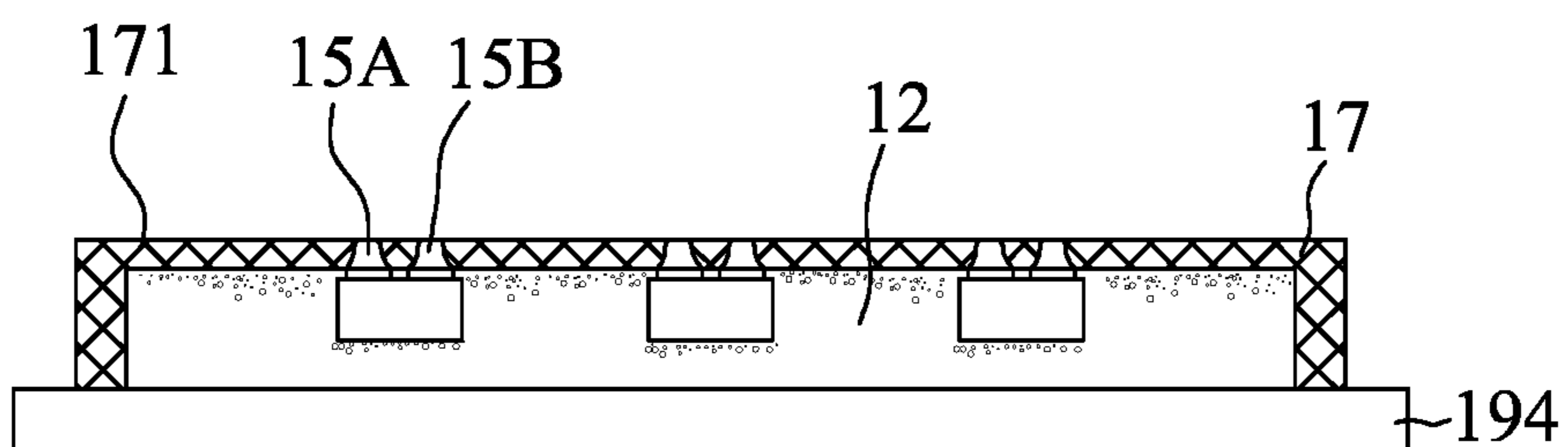


FIG. 3H

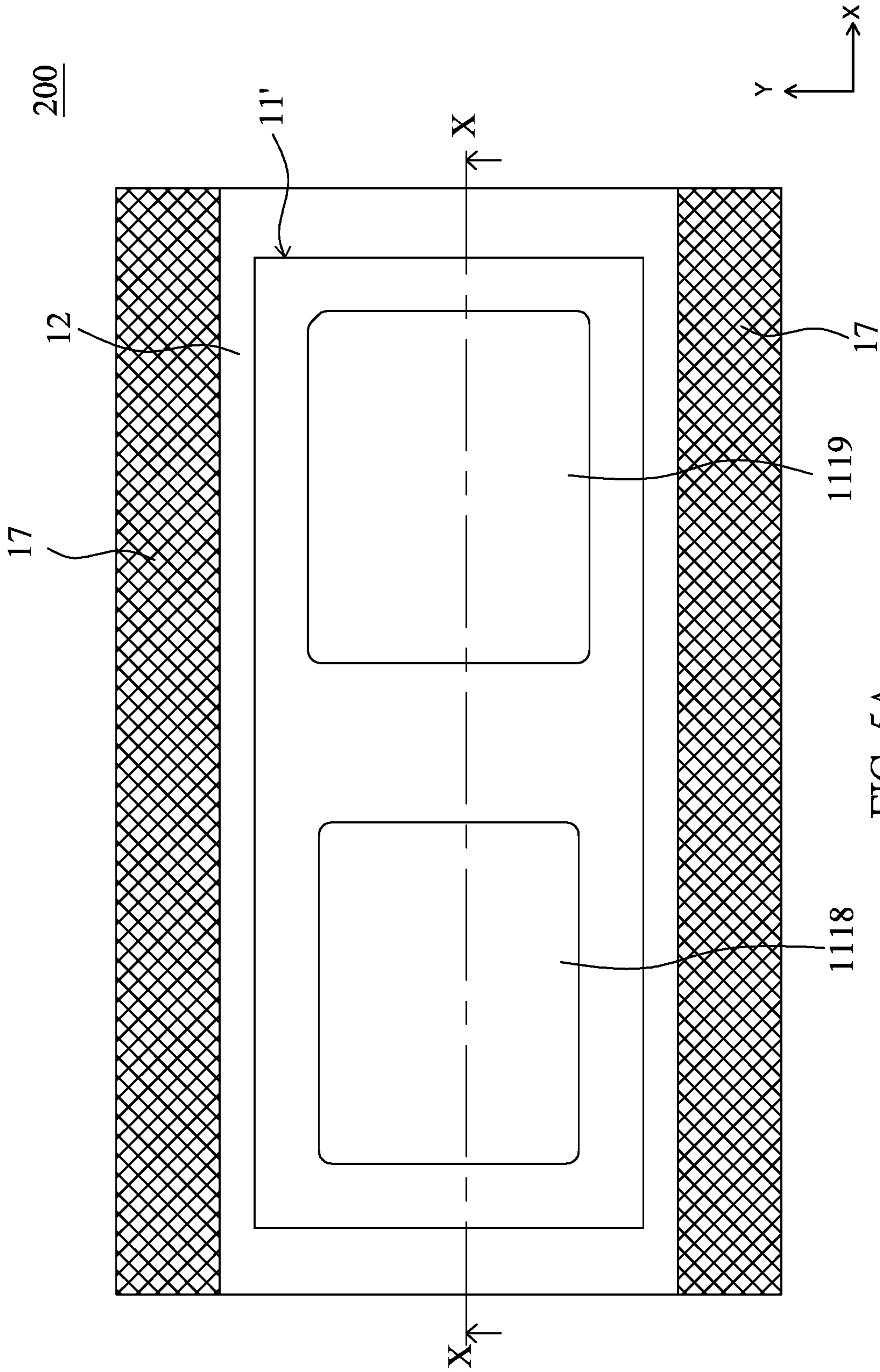


FIG. 5A

200

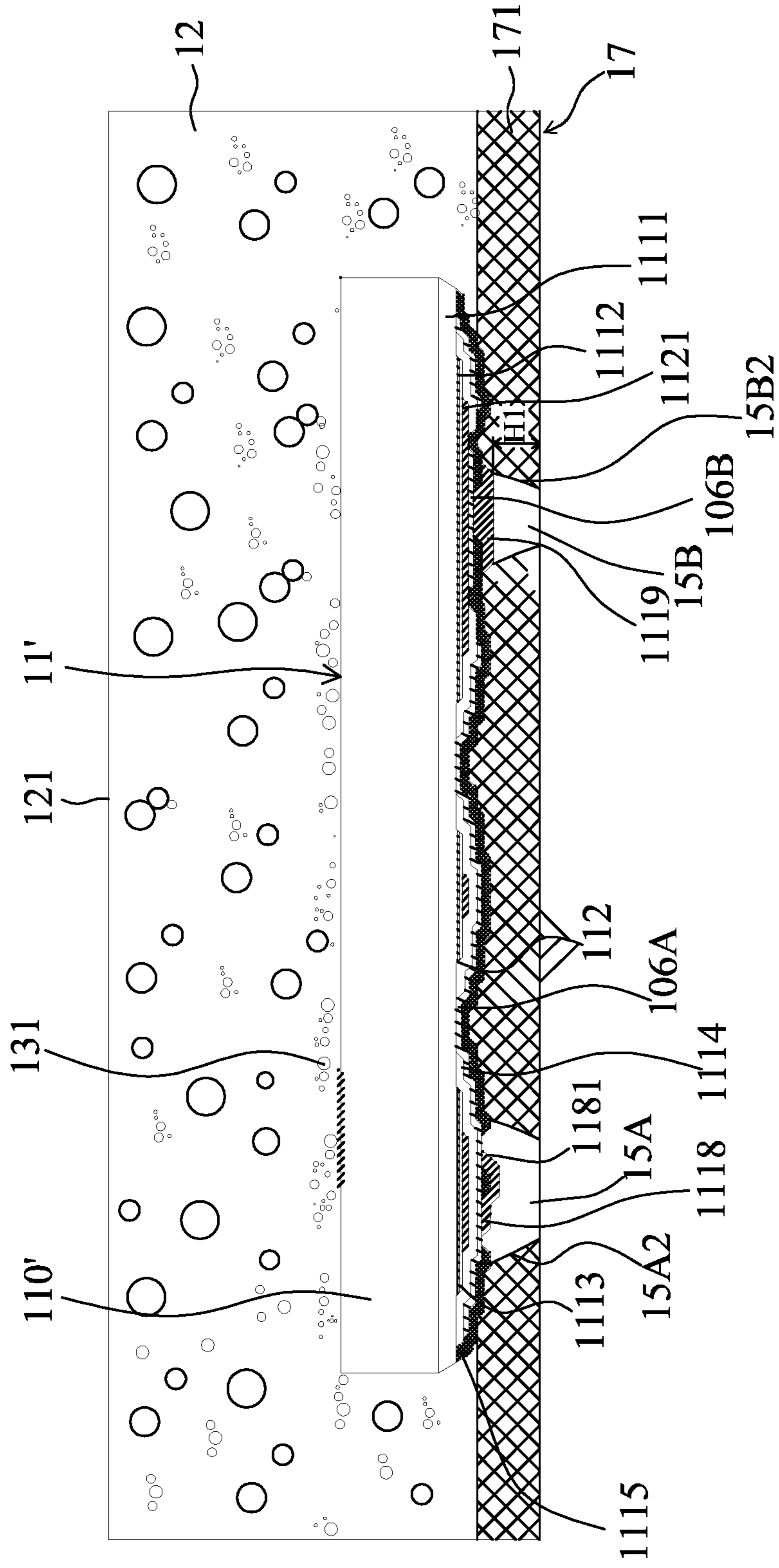


FIG. 5B



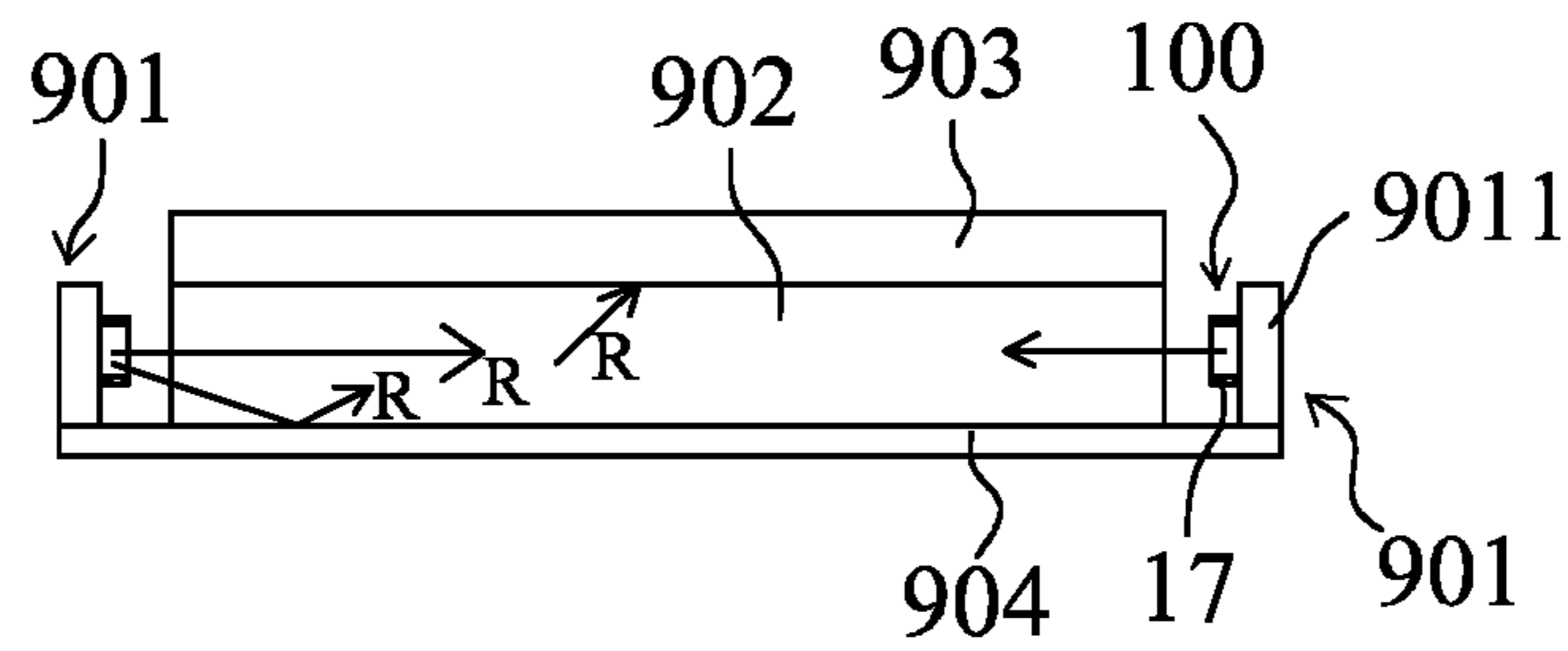


FIG. 6A

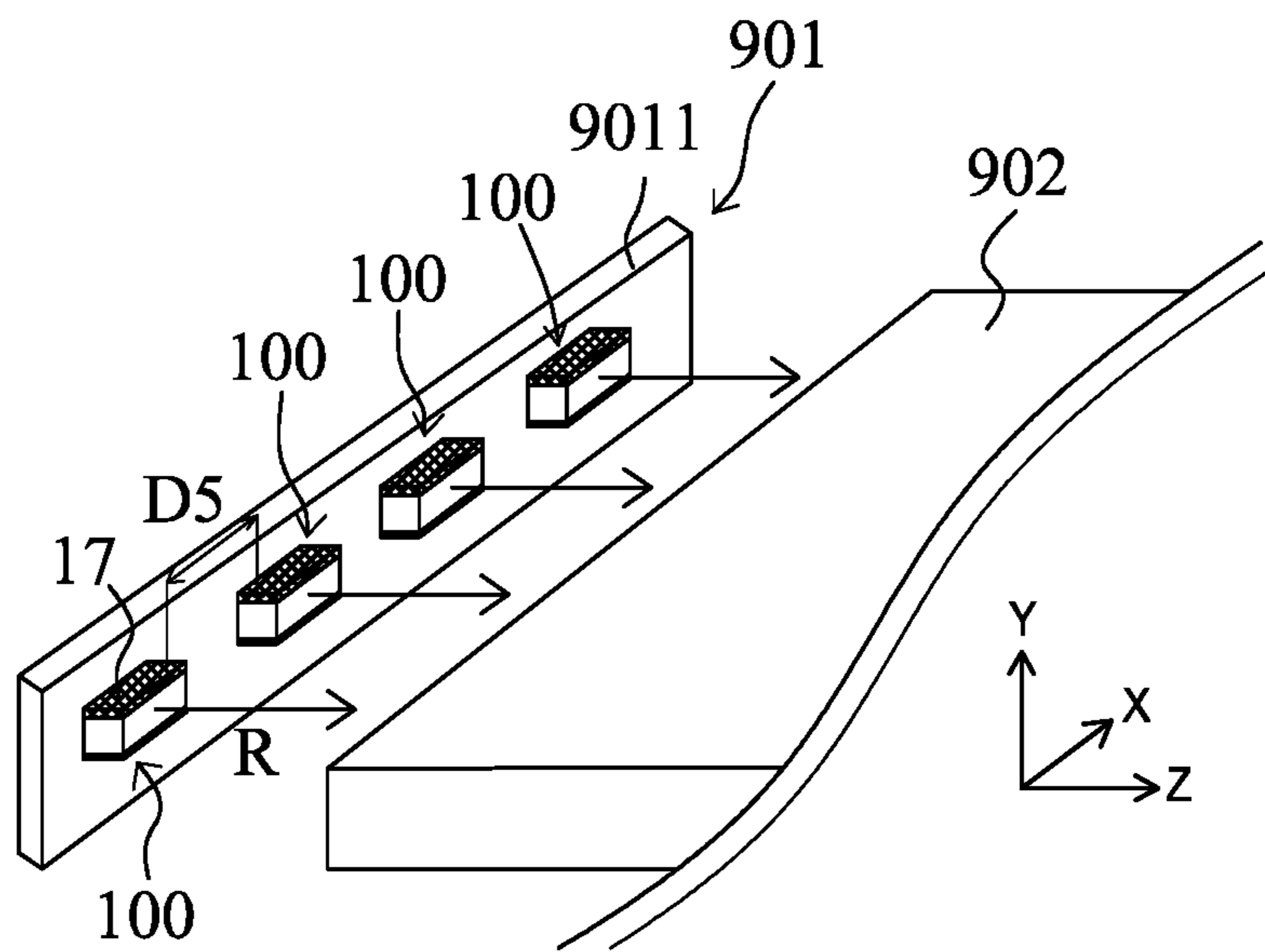


FIG. 6B

## LIGHT-EMITTING DEVICE

## TECHNICAL FIELD

The present disclosure relates to a light-emitting device and in particular to a light-emitting device comprising a reflective layer covering two sides of a light-transmitting body.

## DESCRIPTION OF THE RELATED ART

The light-emitting diodes (LEDs) have the characteristics of low power consumption, long operational life, small volume, quick response and stable opto-electrical property of emitted light. Recently, the light-emitting diodes gradually are used in a backlight module of a liquid crystal display.

## SUMMARY OF THE DISCLOSURE

A light-emitting device includes a light-emitting structure with an electrode layer, a light-transmitting body, a reflective layer and a metal bump. The light-transmitting body covers the light-emitting structure, and has a first side surface and a second side surface which are substantially perpendicular to each other. The reflective layer covers the first side surface without covering the second side surface. The metal bump is directly formed on the electrode layer.

The following description illustrates embodiments and together with drawings to provide a further understanding of the disclosure described above.

## BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1A shows a top view of a light-emitting device in accordance with an embodiment of the present disclosure.

FIG. 1B shows a cross-sectional view taken along lines X-X of FIG. 1A.

FIG. 1C shows a cross-sectional view taken along lines Y-Y of FIG. 1A.

FIG. 1D shows an enlarged view of a circled area A in FIG. 1B.

FIG. 1E shows an enlarged view of a circled area B in FIG. 1C.

FIG. 1F shows a bottom view of a light-emitting device in accordance with an embodiment of the present disclosure.

FIGS. 2A~2H show perspective views of making a light-emitting device in accordance with an embodiment of the present disclosure.

FIGS. 3A~3H show cross-sectional views taken along lines II-II of FIGS. 2A~2H, respectively.

FIG. 4A shows a cross-sectional view taken along lines of FIG. 2E.

FIG. 4B shows a cross-sectional view taken along lines of FIG. 2G.

FIG. 5A shows a top view of a light-emitting device in accordance with an embodiment of the present disclosure.

FIG. 5B shows a cross-sectional view taken along lines X-X of FIG. 5A.

FIG. 6A shows a cross-sectional view of an edge-lit backlight unit of a liquid crystal display in accordance with an embodiment of the present disclosure.

FIG. 6B shows a perspective view of a light source and a light-guiding plate.

## DETAILED DESCRIPTION OF THE EMBODIMENTS

The drawings illustrate the embodiments of the application and, together with the description, serve to illustrate the

principles of the application. The same name or the same reference number given or appeared in different paragraphs or figures along the specification should have the same or equivalent meanings while it is once defined anywhere of the disclosure. The thickness or the shape of an element in the specification can be expanded or narrowed. It is noted that the elements not drawn or described in the figure can be included in the present application by the skilled person in the art.

FIG. 1A shows a top view of a light-emitting device 100 in accordance with an embodiment of the present disclosure. For clear illustration, FIG. 1A only shows some layers and each layer is drawn in solid line (a conductive layer 1116 is drawn in dot line and will be described later) regardless of its material being non-transparent, transparent, or semi-transparent. FIG. 1B shows a cross-sectional view taken along lines X-X of FIG. 1A. FIG. 1C shows a cross-sectional view taken along lines Y-Y of FIG. 1A. FIG. 1D shows an enlarged view of a circled area A in FIG. 1B. FIG. 1E shows an enlarged view of a circled area B in FIG. 1C. FIG. 1F shows a bottom view of the light-emitting device 100. For simplified illustration, a light-emitting structure 11 or light-emitting body 111A is shown as cuboid in FIGS. 1B and 1C, and the detailed structure will be described in FIGS. 1D and 1E.

Referring to FIGS. 1A, 1B, and 1D, the light-emitting device 100 includes a light-emitting structure 11, a light-transmitting body 12, a wavelength-conversion body 13, metal bump 15A, 15B, and a reflective layer 17. The light-emitting structure 11 includes a patterned substrate 110 and two light-emitting bodies 111A, 111B. The patterned substrate 110 is substantially a cuboid and includes a top surface 1101, a bottom surface 1102 opposite to the top surface 1101, and four side surfaces (a first side surface 1103, a second side surface 1104, a third side surface 1105, and a fourth side surface 1106) connecting between the top surface 1101 and the bottom surface 1102. The bottom surface 1102 is a patterned surface with a concave-convex structure in a regular or irregular arrangement. The light-transmitting body 12 covers the top surface 1101, the four side surfaces 1103~1106 and a portion of the bottom surface 1102.

Referring to FIG. 1D, the light-emitting structure 11 includes the patterned substrate 110, the two light-emitting bodies 111A, 111B commonly formed on the patterned substrate 110, a trench 112 formed between the two light-emitting bodies 111A, 111B such that the two light-emitting bodies 111A, 111B are physically separated from each other. Each light-emitting body 111A, 111B includes a first-type semiconductor layer 1111, an active layer 1112, and a second-type semiconductor layer 1113. A first insulation layer 1114 is formed in the trench 112 and covers the first-type semiconductor layers 1111 of the light-emitting bodies 111A, 111B to avoid undesired electrical path (short circuit). A mirror layer 1121 is formed on the second-type semiconductor layer 1113. A second insulation layer 1115 is formed on the first insulation layer 1114, the second-type semiconductor layers 1113 of the light-emitting bodies 111A, 111B and the mirror layer 1121 to expose the mirror layer 1121 and a portion of the second-type semiconductor layer 1113 of the light-emitting body 111B. A conductive layer 1116 is formed on the second insulation layer 1115. In addition, the second insulation layer 1115 covers a sidewall of the first insulation layer 1114. The conductive layer 1116 covers a portion of a sidewall of the second insulation layer 1115 and extends to the mirror layer 1121 of the light-emitting body 111B. A third insulation layer 1117 is formed



on the conductive layer 1116, covers the light-emitting bodies 111A, 111B and exposes a portion of the conductive layer 1116. A first electrode layer 1118 and a second electrode layer 1119 are formed on the light-emitting bodies 111A, 111B, respectively. The electrical connection between the light-emitting bodies 111A, 111B is described later. An ohmic contact layer 1120 is optionally formed between the second-type semiconductor layer 1113 and the mirror layer 1121 for lowering a driving voltage of the light-emitting device 100.

For clear illustration, the conductive layer 1116 of FIG. 1A is drawn in a dot line. Referring to FIGS. 1A, 1D, and 1E, the conductive layer 1116 has a first region 1161, a second region 1162 (the hatch area in FIG. 1A) and a third region 1163. The first region 1161 is formed merely on the light-emitting body 111A and physically separated from the second region 1162. The second region 1162 surrounds the first region 1161. The second region 1162 contacts the first-type semiconductor layer 1111 of the light-emitting body 111A, and is further formed on the second insulation layer 1115 in the trench 112 to extend to the second-type semiconductor layer 1113 of the light-emitting body 111B so the conductive layer 1116 serially connects the light-emitting body 111A with the light-emitting body 111B (due to the position of X-X line, the electrical connection is not shown in FIG. 1D).

Referring to FIGS. 1A, 1D and 1E, a plurality of holes 1110 is formed in the third insulation layer 1110, and the holes 1110 are formed merely on the light-emitting body 111A and not formed on the light-emitting body 111B. The first electrode layer 1118 extends into the holes 1110 and electrically connected to the first region 1161 of the conductive layer 1116 on the light-emitting body 111A so the first electrode layer 1118 is electrically connected to the second-type semiconductor layer 1113 of the light-emitting body 111A. The third region 1163 of the conductive layer 1116 is formed merely on the light-emitting body 111B. The second electrode layer 1119 contacts directly the third region 1163 of the conductive layer 1116 exposed from the third insulation layer 1117. The third region 1163 of the conductive layer 1116 contacts the first-type semiconductor layer 1111 of the light-emitting body 111B. In this embodiment, for example, when the first electrode layer 1118 is electrically connected to a positive terminal of an external electrode and the second electrode layer 1119 is electrically connected to a negative terminal of the external electrode, a current flows through the first electrode layer 1118 in the holes, the first region 1161 of the conductive layer 1116, the second-type semiconductor layer 1113 of the light-emitting body 111A, the active layer 1112 of the light-emitting body 111A, the first-type semiconductor layer 1111 of the light-emitting body 111A, the second region 1162 of the conductive layer 1116, the second-type semiconductor layer 1113 of the light-emitting body 111B, the active layer 1112 of the light-emitting body 111B, the first-type semiconductor layer 1111 of the light-emitting body 111B, the third region 1163 of the conductive layer 1116 and to the second electrode layer 1119, so the light-emitting bodies 111A, 111B are electrically connected with each other in series and emit light. Moreover, based on the aforesaid structure, a process of forming holes 1110 on the light-emitting body 111B can be eliminated and the conductive layer 1116 covers the sidewalls of the light-emitting bodies 111A, 111B for enhancing the luminous flux (lumen) of the light-emitting device 100 and reducing the forward voltage of the light-emitting device 100.

In this embodiment, the first electrode layer 1118, the second electrode layer 1119 and the conductive layer 1116 can be made of metal, for example Au, Ag, Cu, Cr, Al, Pt, Ni, Ti, Sn or alloy thereof. The mirror layer 1121 can reflect light emitted from the light-emitting body and includes Ag, Al, or Distributed Bragg Reflector (DBR). The first insulation layer 1114 can be a single layer or a multilayer. When the first insulation layer 1114 is a single layer, it can comprise oxide, nitride, or polymer. The oxide can comprise  $\text{Al}_2\text{O}_3$ ,  $\text{SiO}_2$ ,  $\text{TiO}_2$ ,  $\text{Ta}_2\text{O}_5$ ,  $\text{AlO}_x$ . The nitride can comprise MN or  $\text{SiN}_x$ . The polymer can comprise polyimide or BCB. When the first insulation layer 1114 is a multilayer, it can be a stack structure for forming a Distributed Bragg Reflector whose material comprising  $\text{Al}_2\text{O}_3$ ,  $\text{SiO}_2$ ,  $\text{TiO}_2$ ,  $\text{Ta}_2\text{O}_5$ , or  $\text{SiN}_x$ . The second insulation layer 1115 and the third insulation layer 1117 comprise a material referred to the material of the first insulation layer 1114.

Referring to FIGS. 1A, 1B and 1C, the light-transmitting body 12 encloses the light-emitting structure 11 and is substantially a cuboid. Accordingly, the light-transmitting body 12 is a rectangular in FIG. 1A. The light-transmitting body 12 has a top surface 121, a bottom surface 122 opposite to the top surface 121, and four side surfaces (a first side surface 123, a second side surface 124, a third side surface 125 and a fourth side surface 126) connecting between the top surface 121 and the bottom surface 122. In FIG. 1A, the first side surface 123 and the third side surface 125 are substantially parallel to each other and face each other, and they are the longer sides of the rectangle. The second side surface 124 and the fourth side surface 126 are substantially parallel to each other and face each other, and they are the shorter sides of the rectangle. The first side surface 123 is substantially perpendicular to the second side surface 124. The reflective layer 17 includes a side portion 170 and a bottom portion 171. The side portion 170 covers the first side surface 123 and the third side surface 125 without covering the second side surface 124 and the fourth side surface 126. The bottom portion 171 covers the bottom surface 122. The top surface 121 is not covered by the reflective layer 17. Similarly, the reflective layer 17 covers the side surface 1103 and the third side surface 1105 of the light-emitting structure 11 without covering the second side surface 1104 and the fourth side surface 1106.

Referring to FIG. 1C, the side portion 170 has an outer surface 175 and an inner surface 176. The outer surface 175 is substantially flat and perpendicular to the top surface 121. The inner surface 176 is an inclined surface inclined with respect to the top surface by an angle ( $\theta$ ) of  $60^\circ\sim 80^\circ$ . Specifically, a distance (D1) between the inner surface 176 and the outer surface 175 is gradually increased in a direction from the top surface 121 to the bottom surface 122 of the light-transmitting body 12. The inner surface 176 reflects the light emitted from the light-emitting structure 11 toward the top surface 121 of the light-transmitting body 12. In other words, the reflective layer 17 reflects the light emitted from the light-emitting structure 11 toward the top surface 121 or/and side surfaces 124, 126 of the light-transmitting body 12 to exit the light-emitting device 100.

Furthermore, the reflective layer 17 is a mixture including a matrix and a plurality of reflective particles dispersed in the matrix so reflection of the light emitted from the light-emitted structure 11 occurs within the reflective layer 17 and the reflection is called diffuse reflection. The matrix is an insulation material and includes silicone-based material or epoxy-based material. The reflective particle includes  $\text{TiO}_2$ ,  $\text{SiO}_2$ ,  $\text{BaSO}_4$ , or  $\text{Al}_2\text{O}_3$ . Since the thickness of the reflective layer 17 correlates with its reflectivity which varies with



wavelength, the thickness of the reflective layer **17** (the maximum distance between the inner surface **176** and the outer surface **175**) ranges from 50  $\mu\text{m}$ ~160  $\mu\text{m}$ . When the thickness of the reflective layer **17** is less than 50  $\mu\text{m}$ , the reflective layer **17** has a reflectivity of less than 90% at 430 nm~450 nm, has a reflectivity of less than 88% at 540 nm~570 nm, and has a reflectivity of less than 80% at 620 nm~670 nm. When the thickness of the reflective layer **17** is about 160  $\mu\text{m}$ , the reflective layer **17** has a reflectivity of greater than 95% at 430 nm~450 nm, at 540 nm~570 nm, and at 620 nm~670 nm. However, the thickness of the reflective layer **17** is greater than 160  $\mu\text{m}$ , which results in an increase in the thickness of the light-emitting device **100** and the cost for making thereof for limiting the applicability, for example, mobile phone, liquid crystal display, wearable apparatus like watch, wristband, ring, and so on. In another embodiment, based on various applications, the reflective layer **17** has a thickness greater than 160  $\mu\text{m}$ , or in a range of 50  $\mu\text{m}$ ~1000  $\mu\text{m}$ .

Referring to FIGS. **1B**, **1D** and **1F**, the bottom portion **171** of the reflective layer **17** is formed on the bottom surface **122** and has a first part **1711**, a second part, **1712** and a third part **1713**. As shown in FIG. **1D**, the first part **1711**, the second part, **1712** and the third part **1713** are separated from each other. The first part **171** covers the metal bump **15A**, the second part **1712** covers the metal bumps **15A**, **15B**, and the third part **1713** covers the metal bump **15B**. As shown in FIG. **1F**, actually, the first part **1711**, the second part, **1712** and the third part **1713** are connected to each other.

Metal bump **15A**, **15B** contact and are electrically connected to the first electrode layer **1118** and the second electrode layer **1119**, respectively. Each of the metal bumps **15A**, **15B** has a substantially flat bottom surface **15A1**, **15B1**. In addition, the bottom portion **171** also has a substantially flat bottom surface **1714**. The definition of “substantially flat” herein is when the light-emitting device **100** is observed by scanning electron microscope (SEM) at 60 $\times$ ~100 $\times$  magnification, the bottom surface **15A1**, **15B1**, **1714** are not substantially and severely rugged. However, when the light-emitting device **100** is observed by scanning electron microscope (SEM) at larger than 400 $\times$  magnification, or measured by atomic force microscope (AFM), the bottom surface **15A1**, **15B1**, **1714** are rough with a roughness of 2~3  $\mu\text{m}/\text{mm}^2$ .

The metal bump (**15A**, **15B**) includes a lead-free solders containing at least one material selected from the group consisting of tin, copper, silver, bismuth, indium, zinc, and antimony. The metal bumps **15A**, **15B** have a height (H1) between 20  $\mu\text{m}$ ~150  $\mu\text{m}$ . In one embodiment, the metal bump is formed by using reflow soldering process. Specifically, a solder paste is placed on the electrode layer and then heated in a reflow oven to melt the solder paste and create a joint, thereby forming the metal bumps **15A**, **15B**. The solder paste can include Sn—Ag—Cu, Sn—Sb or Au—Sn, and have a melting point greater than 215° C., or greater than 220° C., or of 215° C.~240° C. (for example, 217° C., 220° C., 234° C.) In addition, a peak temperature in the reflow soldering process (the peak temperature is usually happened in a stage, called “reflow zone”) is greater than 250° C., or greater than 260° C., or of 250° C.~270° C. (for example, 255° C., 265° C.).

Referring to FIG. **1F**, the metal bumps **15A**, **15B** have a plurality of scratched lines **151** formed thereon and the scratched lines **151** can be observed by optical microscope. The scratched lines **151** can also extend to areas other than the metal bumps **15A**, **15B**, such as the bottom surface **1714** of the reflective layer **17**. Specifically, the scratched line **151**

is substantially straight line which is continuously extended over the bottom surfaces **1714**, **15A1**, **15B1**. The detailed description will be discussed later.

Referring to FIGS. **1B** and **1C**, the wavelength conversion body **13** is formed within the light-transmitting body **12**. In this embodiment, the wavelength conversion body **13** includes a plurality of wavelength conversion particles **131** dispersed in a matrix. The wavelength conversion particles **131** covers the top surface **1102**, the first side surface **1103**, the second side surface **111**, a portion of the third side surface **1105** and a portion of the fourth side surface **1106**. A portion of the third side surface **1105** and a portion of the fourth side surface **1106** are not covered by the wavelength conversion particles **131**. Alternatively, the wavelength-conversion body **13** and/or the light-transmitting body **12** further include diffusion powder. The matrix includes epoxy, silicone, PI, BCB, PFCB, Acrylic resin, PMMA, PET, PC or polyetherimide. The light-transmitting body **12** includes epoxy, silicone, PI, BCB, PFCB, Acrylic resin, PMMA, PET, PC or polyetherimide. When the matrix of the wavelength-conversion body **13** has a material same as the light-transmitting body **12**, an interface therebetween observed by scan electron microscope (SEM) is vague and unclear. Or, there is no interface existing between the wavelength-conversion body **13** and the light-transmitting body **12**, that is, the wavelength-conversion particles dispersed in the light-transmitting body **12**.

The wavelength conversion particles **131** have a particle size of 5  $\mu\text{m}$ ~100  $\mu\text{m}$  and include one or more (a plurality of) kinds of inorganic phosphor, organic fluorescent colorants, semiconductors, or combinations thereof. The inorganic phosphor includes but is not limited to, yellow-greenish phosphor or red phosphor. The yellow-greenish phosphor comprises aluminum oxide (such as YAG or TAG), silicate, vanadate, alkaline-earth metal selenide, or metal nitride. The red phosphor includes fluoride ( $\text{K}_2\text{TiF}_6:\text{Mn}^{4+}$ ,  $\text{K}_2\text{SiF}_6:\text{Mn}^{4+}$ ), silicate, vanadate, alkaline-earth metal sulfide (CaS), metal nitride oxide, a mixture of tungstate and molybdate. The weight percentage (w/w) of the wavelength-conversion particles within the matrix is between 50%~70%. The semiconductors include crystal with nano-sizes, for example, quantum dot. The quantum dot can be ZnS, ZnSe, ZnTe, ZnO, CdS, CdSe, CdTe, GaN, GaP, GaSe, GaSb, GaAs, AlN, AlP, AlAs, InP, InAs, Te, PbS, InSb, PbTe, PbSe, SbTe, ZnCdSeS, CuInS, CsPbCl<sub>3</sub>, CsPbBr<sub>3</sub>, or CsPbI<sub>3</sub>.

The diffusing powder includes titanium dioxide, silicon dioxide, aluminum oxide, zinc oxide, or zirconium dioxide for diffusing the light emitted from the light-emitting structure **11**. The weight percentage (w/w) of the diffusing powder within the matrix is between 0.1%~0.5% and has a particle size between 10 nm~100 nm or between 10  $\mu\text{m}$ ~50  $\mu\text{m}$ . In an embodiment, the weight percentage of the diffusing powder (or the wavelength-conversion particles) within the matrix can be measured by a thermogravimetric analyzer (TGA). Specifically, the matrix is removed (through evaporation or pyrolysis) by increasing the temperature to a certain temperature so the diffusing powder (or the wavelength-conversion particles) is remained. The change of the weight can be measured and the weight of the matrix and the weight of the diffusing powder (or the wavelength-conversion particles) can be respectively derived from the change of the weight, and the weight percentage of the diffusing powder within the matrix can be calculated. Or, the total weight of the matrix and the diffusing powder (or the wavelength-conversion particles) can be measured first, and a solvent is applied to remove the matrix so the weight of the



diffusing powder (or the wavelength-conversion particles) can be measured. Then, the weight percentage of the diffusing powder (or the wavelength-conversion particles) within the matrix can be calculated.

The wavelength conversion particles **131** can absorb a first light emitted from the light-emitting structure **11** and convert the first light to a second light having a spectrum different from that of the first light. The first light is mixed with the second light to produce a third light. In this embodiment, the third light has chromaticity coordinates (x, y) on CIE 1931 chromaticity diagram, wherein  $0.27 \leq x \leq 0.285$ ;  $0.23 \leq y \leq 0.26$ . In another embodiment, the first light is mixed with the second light to produce a third light, such as a white light. Based on the weight percentage and the material of the wavelength-conversion particles, the light-emitting device has a correlated color temperature of about 2200K~6500K (ex. 2200K, 2400K, 2700K, 3000K, 5000K, 5700K, 6500K) under a thermal stable state with a color point (CIE x, y) within a seven-step MacAdam ellipse. In another embodiment, the first light is mixed with the second light to produce purple light, amber light, green light, yellow light or other non-white light.

In FIGS. 1A~1C, the first side surface **123** and the third side surface **125** are covered by the reflective layer **17**, and the bottom surface **122** is also covered by the reflective layer **17**, therefore, the light-emitting device **100** has three light emitting surfaces. In other words, the light emitted from the light-emitting structure **11** pass directly through the top surface **121**, the second side surface **124** and the fourth side surface **126** of the light-transmitting body **12** to exit the light-emitting device **100**. The light-emitting angle of the light-emitting structure **11** is about  $140^\circ$  so more than 50% of light emits outward from the top surface **1101** (or the top surface **121** of the light-transmitting body **12**). The top surface **1101** of the light-emitting structure **11** is defined as a main light-emitting surface. The light-emitting directions of the light-emitting structure **11** and the light-emitting device **100** are identical, that is, light emit outward along the Z axis (exiting the light-emitting device **100**). Accordingly, the main light-emitting surface of the light-emitting structure **11** and the light-emitting surface of the light-emitting device **100** are substantially parallel to each other. The light-emitting angle is defined as a range of angle from the angle of maximum luminous intensity to the angle of half (50%) of the maximum luminous intensity. The detailed description of the light-emitting angle can be referred to the content disclosed in the TW patent application 103104105.

In one embodiment, the reflective layer **17** includes metal such as Au, Ag, Cu, Al, Pt, Ni, or Rh. Accordingly, reflection of the light emitted from the light-emitted structure **11** occurs at the reflective layer **17** and the reflection is called specular reflection. In addition, when the reflective layer **17** is metal and has a thickness of 50~200 Å, its reflectivity is 99% so a thickness of the light-emitting device **100** in the Y direction can be reduced and the applicability of the light-emitting device **100** (for example, mobile phone, liquid crystal display, wearable apparatus (watch, wristband, ring, etc.)) is therefore increased. The reflective layer **17** can be formed on the light-transmitting body **12** by sputtering, electroplating or chemical plating. Alternatively, an adhesive (not shown), such as  $\text{TiO}_2$ , can be formed between the reflective layer **17** and the light-transmitting body **12** for improving adhesion therebetween. Or, the light-transmitting body **12** is undergone a surface treatment (for example, He plasma,  $\text{O}_2$  plasma, or  $\text{N}_2$  plasma) and the reflective layer **17** contacts directly the light-transmitting body **12**). The

surface treatment improves adhesion between the reflective layer **17** and the light-transmitting body **12**.

Two light-emitting bodies in FIG. 1A are electrically connected in series. In another embodiment, the light-emitting structure **11** can include one light-emitting body, or at least two or not less than two light-emitting bodies which are electrically connected in series, in parallel or series-parallel or bridge. When the light-emitting structure includes a plurality of light-emitting bodies, the plurality of light-emitting bodies can be commonly formed on one substrate, or each of the plurality of light-emitting bodies has a substrate and then being mounted on a carrier. Alternatively, some of the light-emitting bodies are commonly formed on a substrate, and other light-emitting bodies have respective substrates and then are mounted commonly on a carrier. In addition, two light-emitting bodies in this embodiment are flip-chip structures and are electrically connected to each other by a conductive layer. In another embodiment, two light-emitting bodies are horizontal structure and are electrically connected to each other through wire bonding.

When the aforesaid light-emitting body has a heterostructure, the first-type semiconductor layer and the second-type semiconductor layer, for example a cladding layer or a confinement layer, provide holes and electrons, respectively, and each type layer has a bandgap greater than that of the active layer, thereby increasing the probability of electrons and holes combining in the active layer to emit light. The first-type semiconductor layer, the active layer, and the second-type semiconductor layer can be made of III-V group semiconductor materials, such as  $\text{Al}_x\text{In}_y\text{Ga}_{(1-x-y)}\text{N}$  or  $\text{Al}_x\text{In}_y\text{Ga}_{(1-x-y)}\text{P}$ , wherein  $0 \leq x, y \leq 1$ ;  $(x+y) \leq 1$ . Depending on the material of the active layer, the light-emitting diode can emit a red light with a peak wavelength or dominant wavelength of 610~650 nm, a green light with a peak wavelength or dominant wavelength of 530~570 nm, a blue light with a peak wavelength or dominant wavelength of 450~490 nm, a purple light with a peak wavelength or dominant wavelength of 400~440 nm, or a UV light with a peak wavelength of 200~400 nm.

FIGS. 2A~2H show perspective views of making a light-emitting device in accordance with an embodiment of the present disclosure. FIGS. 3A~3H show cross-sectional views taken along line II-II of FIGS. 2A~2H, respectively. For simplification, the light-emitting structure **11** is shown as cuboid in FIGS. 2A~2H and FIGS. 3A~3H for exemplary illustration. The shape of the light-emitting structure **11** in top view can also be trapezoid, parallelogram, diamond, triangle, pentagon, hexagon, or round. The detailed structure can be referred to the descriptions of FIGS. 1A~1F.

Referring to FIGS. 2A and 3A, a plurality of light-emitting diodes **11** (nine light-emitting diodes are shown) is disposed on a first temporary tape **191**. The electrode layers **1118**, **1119** are attached to the first temporary tape **191**. In one embodiment, the number and arrangement of light-emitting diodes **11** are exemplary, and not intended to limit the scope of the present disclosure.

Referring to FIGS. 2B and 3B, a transparent body including a plurality of wavelength conversion particles **131** covers the light-emitting structure **11** completely. The light-emitting structures **11** are immersed within the transparent body and not exposed to environment (for example, ambient air). Thereafter, the transparent body is cured to form the light-transmitting body **12**. In one embodiment, the transparent body can be formed on the light-emitting structure **11** by spraying, coating, dispensing or screen printing. If the transparent body is formed on the light-emitting structure **11** by spraying or dispensing, the transparent body has various



heights (Z direction) at different locations across its whole area. After curing, the transparent body is cured to form the light-transmitting body **12** with different heights at different locations.

Moreover, because of gravity, during the curing, the wavelength conversion particles **131** are naturally precipitated and thus most of the wavelength conversion particles **131** can contact the light-emitting structure **11** and a portion of the wavelength conversion particles **131** is attached to the side surface of the light-emitting structure **11** (the detailed description is referred to FIGS. **1B** and **1C**). In another embodiment, it is possible to control the temperature and time of the curing to change distributions of the wavelength conversion particles **131**. For example, the transparent body is fully cured before the wavelength conversion particles **131** do not precipitate near the bottom so the wavelength conversion particles **131** are suspended within the light-transmitting body **12** and do not contact the light-emitting structure **11**. Or, an anti-precipitation agent (such as  $\text{TiO}_2$ ) is added into the transparent body for preventing the wavelength conversion particles **131** from precipitating near the bottom during curing so the wavelength conversion particles **131** can be uniformly dispersed within the light-transmitting body **12**.

In another embodiment, the transparent body with the wavelength conversion particles can be pre-formed as a wavelength conversion sheet and to adhere to the light-emitting structure **11**. The adhesion is established by tightly sealing an upper mold (not shown) and a lower mold (not shown) with heat and pressure for softening the wavelength conversion sheet. Then, the wavelength conversion sheet tightly adheres to the light-emitting structure **11**. Alternatively, the air is extracted out when the upper mold is very close to the lower mold and the wavelength conversion sheet does not contact the light-emitting structure **11**. The bubble between the wavelength conversion sheet and the light-emitting structure **11** can be eliminated and the strength of joint can be enhanced.

Referring to FIGS. **2C** and **3C**, a physical removal process is conducted to planarize the light-transmitting body **12** so the top surface **121** of the light-transmitting body **12** is substantially flat.

Referring to FIGS. **2D** and **3D**, a second temporary tape **194** is provided to attach to the top surface **121** of the light-transmitting body **12**, and then the first temporary tape **191** is removed to expose the electrode layers **1118**, **1119**.

Referring to FIGS. **2E** and **3E**, the structure of FIG. **2D** (or **3D**) is reversed and a cutting process is performed to form a plurality of trenches **231** in the light-transmitting body **12**. The cross-sectional shape of the trenches **231** is determined by the shape and size of the cutter using in the manufacturing. Due to the position of the section line, the trenches **231** is not shown in FIG. **3E**. FIG. **4A** show a cross-sectional view taken along line of FIG. **2E**, and the trenches **231** are shown in FIG. **4A**.

Referring to FIGS. **2F** and **3F**, a solder paste is coated on the electrode layers **1118**, **1119** and a reflow process is performed to form the metal bumps **15A**, **15B** directly contacting the electrode layers **1118**, **1119**. Specifically, the solder paste is applied to the electrode layers **1118**, **1119** and the solder paste has a projection area smaller than the electrode layers **1118**, **1119** and covers only a part of the electrode layers **1118**, **1119**. Because the electrode layers **1118**, **1119** have a bottommost layer made of Au, with the wetting reaction between Au layer and the solder paste, the solder paste will spread out to fully cover the corresponding electrode layers **1118**, **1119**. Furthermore, after the reflow

process, the solder paste can be solidified to form the metal bumps **15A**, **15B**. In this stage, each of the metal bumps **15A**, **15B** is not subjected to a physical removal process (described later) and has a contour without a sharp angle. The metal bumps **15A**, **15B** have a cross-sectional area gradually decreasing along the Z axis. In addition, due to manufacturing deviations, the metal bump **15A** may have a shape different from that of the metal bump **15B**. In FIG. **1B**, the metal bump **15A** has a cross-sectional view different from the metal bump **15B**. The other detailed descriptions of the solder paste can be referred to aforesaid paragraphs and are omitted herein for brevity.

Referring to FIGS. **2G** and **3G**, a plurality of reflective particles is mixed into a matrix to form a paste in an uncured state, wherein the paste includes matrix and reflective particles and has a color determined by the reflective particles, which is generally white. Subsequently, the paste is added to cover the metal bumps **15A**, **15B**, the light-transmitting body **12** and the trenches **231** so the metal bumps **15A**, **15B**, and the light-transmitting body **12** are not exposed to environment (for example, ambient air), wherein the trenches **231** can be completely covered or partially covered by the paste or have bubble remaining in the paste,

Then, the paste is cured to form the reflective layer **17**. The reflective layer **17** has a height greater than that of the metal bumps **15A**, **15B**. The reflective layer **17** can be formed on the light-emitting structure **11** by spraying, coating, dispensing or screen printing. In the embodiment, the paste is formed by spraying or dispensing and has various heights (Z direction) at different locations across its whole area (as shown in FIG. **3G**). After curing, the paste is cured to form the reflective layer **17** having different heights at different locations as well. Likewise, the reflective layer **17** can be a pre-formed sheet and adheres to the light-transmitting body **12**. The description of the adhesion can be referred to the aforesaid paragraphs.

A dam **195** is optionally provided to confine a region. Accordingly, when filling the paste, the paste is confined within the region. Compared to the case without the dam **195**, less amount of the paint is used. The structure showing the paste filling into the trenches **231** is shown in FIG. **4B**.

Referring to FIGS. **2H** and **3H**, the dam **195** is removed. A physical removal process is performed until the metal bumps **15A**, **15B** are exposed. In the physical removal process, a portion of the reflective layer **17** is removed to expose the metal bumps **15A**, **15B**. The physical removal process can be further performed to remove the reflective layer **17** and the metal bumps **15A**, **15B** simultaneously so the bottom surface **1714**, **15A1**, **15A2** are substantially coplanar with each other and the bottom surface **1714**, **15A1**, **15A2** are substantially flat. The other detailed descriptions can be referred to aforesaid paragraphs and are omitted herein for brevity.

In this embodiment, after the physical removal process, the maximum roughness (Ra1) of the bottom surface **15A1**, **15B1** of the metal bumps **15A**, **15B** can be slightly larger than, equal to or slightly smaller than that of the bottom surface **1714** of the reflective layer **17** (Ra2). By alpha step film thickness measuring instrument in a measuring length of 50  $\mu\text{m}$ , the difference (defined as the maximum roughness) between the highest point and the lowest point by measuring the bottom surface **15A1**, **15B1** of the metal bumps **15A**, **15B** is Ra1. Likewise, by measuring the bottom surface **1714** of the reflective layer **17** in a measuring length of 50  $\mu\text{m}$ , the difference between the highest point and the



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lowest point among the bottom surface **1714** of the reflective layer is  $Ra2$ ; wherein  $2\ \mu\text{m} \leq Ra1 \leq 15\ \mu\text{m}$ ;  $2\ \mu\text{m} \leq Ra2 \leq 15\ \mu\text{m}$ ;  $0 \leq |Ra2 - Ra1| \leq 13\ \mu\text{m}$ .

The physical removal process is conducted by machinery cutters. The cutter can be composed of high-carbon steel, diamond, ceramic or BN. During the removal process, only water (no slurry or chemical solution) is provided to lower the temperature which is raised due to friction between the cutter and the material to be cut (for example, the reflective layer or the light-transmitting body or the metal bump), and to wash the residue. Moreover, while the cutter having a hardness larger than that of the material to be cut is selected, a plurality of scratched lines (not shown) which can be observed by optical microscope is formed thereon. In another embodiment, by adjusting cutting parameters (for example, cutting speed or the material of the cutter), the scratched lines may not be observed by optical microscope.

Finally, a cutting step is performed (not shown) and the second temporary tape **194** is removed to form a plurality of light-emitting devices.

The temporary tape **191**, **194** are used as a temporary carrier for mounting the light-emitting structure or the light-emitting device during manufacturing. The temporary tape **191**, **194** includes blue tape, thermal release sheet or tape, UV release tape or polyethylene terephthalate (PET).

FIG. **5A** shows a top view of a light-emitting device **200** in accordance with an embodiment of the present disclosure. For clear illustration, FIG. **5A** only shows some layers and each layer is drawn in solid line regardless of its material being non-transparent, transparent, or semi-transparent. FIG. **5B** shows a cross-sectional view taken along lines X-X of FIG. **5A**. Other views can be referred to the corresponding descriptions of the light-emitting device **100**.

Referring to in FIGS. **5A** and **5B**, the light-emitting device **200** includes a light-emitting structure **11'**, a light-transmitting body **12**, a plurality of wavelength conversion particles **131**, metal bumps **15A**, **15B**, and a reflective layer **17**. As shown in FIG. **5B**, the light-emitting structure **11'** merely includes one light-emitting body. The light-emitting body includes an un-patterned substrate **110'**, a first-type semiconductor layer **1111**, an active layer **1112**, and a second-type semiconductor layer **1113**. In this embodiment, the wavelength conversion particles **131** are dispersed within the light-transmitting body **12** without precipitating near the bottom.

A trench **112** is formed to expose the first-type semiconductor layer **1111**. A first insulation layer **1114** is formed in the trench **112** and covers a portion of the first insulation layer **1114**. A conductive layer **106A** is formed on the first insulation layer **1114** and the first-type semiconductor layer **1111** uncovered by the first insulation layer **1114**. A second insulation layer **1115** is formed to cover a portion of the conductive layer **106A**. A mirror layer **1121** is formed on the second-type semiconductor layer **1113**. A first electrode layer **1118** is formed on the conductive layer **106A** uncovered by the second insulation layer **1115** and is electrically connected to the first-type semiconductor layer **1111** through the conductive layer **106A**. The first electrode layer **1118** does not cover entire the conductive layer **106A** so as to expose a portion of the conductive layer **106A**. A metal bump **15A** is formed to directly contact the first electrode layer **1118** and the conductive layer **106A** exposed from the first electrode layer **1118**. In addition, the metal bump **15A** also covers or directly contacts a portion of the second insulation layer **1115**. An ohmic contact layer is optionally formed between the second-type semiconductor layer **1113**

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and the mirror layer **1121** for lowering a driving voltage of the light-emitting device **200**.

Furthermore, a conductive layer **106B** is further formed on the mirror layer **1121**. The second insulation layer **1115** is further formed to cover a portion of the conductive layer **106B**. A second electrode layer **1119** is formed on the second insulation layer **1115** and the conductive layer **106B** uncovered by the second insulation layer **1115** for electrically connecting to the second-type semiconductor layer **1113**. The metal bump **15B** is formed to directly contact the second electrode layer **1119**. In operation, assuming the first-type semiconductor layer **1111** is a n-type semiconductor layer and the second-type semiconductor layer **1113** is a p-type semiconductor layer, when the light-emitting device is electrically connected to an external circuit, a current flows the metal bump **15B**, the second electrode layer **1119**, the conductive layer **106B**, the mirror layer **1121**, the second-type semiconductor layer **1113**, the active layer **1112**, the first-type semiconductor layer **1111**, the conductive layer **106A**, the first electrode layer **1118** and the metal bump **15A** so the light-emitting device **200** emits light.

The bottom portion **171** of the reflective layer **17** covers and directly contacts the second insulation layer **1115** and sidewalls **15A2**, **15B2** of the metal bumps **15A**, **15B**. The first electrode layer **1118** has a side surface **1181** directly covered by the metal bump **15A**. The side surface **1181** does not directly contact the bottom portion **171**. Other detailed descriptions can be referred to the corresponding paragraphs of the light-emitting device **100**.

FIG. **6A** shows a cross-sectional view of an edge-lit backlight unit of a liquid crystal display in accordance with an embodiment of the present disclosure. The backlight unit includes a light source **901**, a light guide plate **902**, and a diffusing plate **903** disposed on the light guide plate **902**. The light source **901** includes a carrier **9011**, a plurality of light-emitting devices **100** disposed on the carrier **9011**, and a circuit (not shown) formed on the carrier to control the light-emitting devices **100**. The light source **901** is arranged at two side of the light guide plate **902**. When the light-emitting device **100** emits light, since light (R) emits outward in the Z direction (to exit the light-emitting devices **100**), the carrier **9011** is arranged perpendicular to the light guide plate **902** (that is, the light-emitting surface of the light-emitting device **100** is perpendicular to the carrier **9011**) which can effectively directs the light (R) into the light guide plate **902**.

When the light (R) emits into the light guide plate **902**, the light guide plate **903** alters the direction of the light (R) toward the diffusing plate **903**. Optionally, a reflector **904** can be disposed on the light guide plate **902** opposite to the diffusing plate **903** for reflecting the light (R). The metal bumps **15A**, **15B** of the light-emitting device **100** are directly mounted on the circuit of the carrier **9011** through solder. In other words, there is no submount between the metal bumps **15A**, **15B** and the carrier **9011**. In one embodiment, the carrier **9011** and the reflector can be integrally formed as one-piece object and in an L-shape form. In addition, the light-emitting devices **100** are arranged on one side of the light guide plate **902** for reducing making cost and simplifying the assembly.

FIG. **6B** shows a perspective view of a light source **902** and the light-guiding plate **902** of FIG. **6A**. The light-emitting devices **100** are arranged along the X direction to form one-dimensional array. The reflective layer **17** is parallel to the long side of the carrier **9011**. In this embodiment, the number and arrangement of the light-emitting device **100** is illustrative, and not intended to limit the scope of the



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present disclosure. Since the light-emitting device **100** has the light-emitting angle of 130~150° in the long side direction (X direction), the distance (D5) between two adjacent light-emitting devices **100** ranges from 12 mm to 15 mm which does not cause dark area in the light guide plate **902**. Based on different application, the distance (D5) can range from 4 mm to 15 mm.

It will be apparent to those having ordinary skill in the art that various modifications and variations can be made to the devices in accordance with the present disclosure without departing from the scope or spirit of the disclosure. In view of the foregoing, it is intended that the present disclosure covers modifications and variations of this disclosure provided they fall within the scope of the following claims and their equivalents.

What is claimed is:

1. A light-emitting device comprising:
  - a light-emitting structure having a top surface, a bottom surface opposite to the top surface, a plurality of lateral surfaces between the top surface and the bottom surface, and an electrode layer;
  - a light-transmitting body fully covering the top surface and the plurality of lateral surfaces of the light-emitting structure, and having a first side surface and a second side surface which are substantially perpendicular to each other;
  - a reflective layer covering the first side surface without covering the second side surface; and
  - a metal bump directly formed under the electrode layer, wherein the reflective layer has a bottommost surface having a plurality of scratched lines formed thereon.
2. The light-emitting device according to claim 1, wherein the bottom surface is covered by the reflective layer.
3. The light-emitting device of claim 1, wherein the light-transmitting body further has a third side surface and a

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fourth side surface, and the reflective layer covers the third side surface without covering the fourth side surface.

4. The light-emitting device of claim 3, wherein the first side surface faces the third side surface, and the second side surface faces the fourth side surface.

5. The light-emitting device of claim 1, wherein the metal bump has a sidewall covered by the reflective layer.

6. The light-emitting device of claim 1, wherein the light-emitting structure has an insulation layer having a portion covered by the metal bump.

7. The light-emitting device of claim 6, wherein the reflective layer covers the insulation layer.

8. The light-emitting device of claim 1, wherein the reflective layer has an inclined inner surface.

9. The light-emitting device of claim 8, wherein the bottom surface is inclined with respect to the inclined inner surface by an angle of 60°-80°.

10. The light-emitting device of claim 1, further comprising a plurality of wavelength conversion particles or a plurality of kinds of wavelength conversion particles.

11. The light-emitting device of claim 1, wherein the light-emitting structure comprises a patterned substrate and at least two light-emitting bodies commonly formed on the patterned substrate.

12. The light-emitting device of claim 1, wherein the light-emitting device merely has three light-emitting surfaces.

13. A backlight unit comprising:

a light guide plate;

a diffusing plate disposed on the light guide plate;

a light source disposed on one side of the light guide plate, and having a carrier and the light-emitting device of claim 1 disposed on the carrier.

14. A liquid crystal display comprising the backlight unit of claim 13.

\* \* \* \* \*